FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT
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Enhancement of the ventilation system in an industrial plot

Study of a warehouse building and a cooking school

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Cover picture: kitchen of the studied cooking school. Photo: Javier Iglesias Estellés, 2018.

Abstract

The motivation of this project is found on the past trend of growing greenhouse gases emissions and, also growing, energy use over the world that still remains. This trend overlaps with a more recent increase in the awareness regarding the effects of human activities towards the Earth ecosystems. Thus, the upgrade of the already-in-use systems is necessary to move towards greener and more modern technologies that permit continue with the economic growth while building more sustainable societies.

Thereby, the research focus on the improvement of the ventilation system of a warehouse building and a cooking school located in the same plot, in an industrial area in Gävle, Sweden. The current system conditions, even consisting in some cases in recirculating air handling units, doesn't permit the utilisation of the waste heat by bringing it back to the system.

The strategy used during the project follows an action research scheme: looking the system, thinking the proper solution and finally acting on the system. The study was approached as an energy audit: with several meetings with the company, collecting airflows data with the thermo-anemometer device, sketching the required building drawings and designing the optimal solution for the company.

Finally, the project resulted in the selection of the proper air handling unit, equipped with a heat recovery system, and the design of its ventilation duct system that permit a heat energy savings of about 67 %. Furthermore, the occupancy study helped design the new scheduling for the ventilation periods that reduce the use of the ventilation system in 30 %. Thus, obtaining a significant energy use reduction that results in a sizeable energy cost saving.

Keywords: Ventilation, warehouse, cooking school, efficiency measures, heat recovery ventilation, Gävle, energy audit.

Preface

I would like to show my deepest gratitude to Arman Ameen and Roland Forsberg, for their supervision and guidance through this project that has being in constant evolution since the very first day.

Secondly, I would like to thank Taghi Karimipanah for its help with the ventilation ducts calculation.

Likewise, I would like to acknowledge Sweco for its collaboration with the project providing the required measuring instruments, and the company manager for its implication and accuracy in the provided information.

Additionally, I would like to thank my brother for his patience during the long asking rounds regarding technical design details.

And last but not least, this project could not have been performed with the collaboration of all those people that surround me and that encouraged me when it was needed.

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Nomenclature

GHG. GreenHouse Gases.

IV. Industrial Ventilation.

HRV. Heat Recovery Ventilation.

AHU. Air Handling Unit.

DH. District Heating.

TF1. Air handling unit that provides air to the offices in the warehouse building.

TF2. Air handling unit that provides air to the central space of the warehouse building.

TF3. Air handling unit that provides air to the back space of the warehouse building.

TF4. Air handling unit that provides air to the cooking school building.

1 Introduction

1.1 Background

The population growth in the last decades and the consumption habits that have been established in the nowadays time has led to a huge increase in the energy use and thus the CO_2 emissions.

Only taking a view in the last decade, the CO_2 emissions increased about a 3 % per year in average, reaching a new record of 34.5 billion tonnes of CO_2 released to the atmosphere in the year 2012. Considering all the emitted greenhouse gasses, the equivalent carbon dioxide (CO_2e) escalates to about 50 billion tonnes in 2012, being forecasted to rise to 58 billion tonnes CO_2e in 2020. (Fichtinger *et al.*, 2015)

That increase of the energy use happens in parallel with an increasing concern regarding the effects of human activities on the Earth ecosystems. In this scenario of environmental awareness and concern about human effects, an improvement of the system efficiencies is required in order to solve the problem, but complemented with a change on the system itself so the reduction of pollutants was enough to start moving to sustainable greener ways of living and growing.

Even though environmental awareness is spreading among different communities, to move to a more optimised way of energy use, there is still a huge work to reach out to all the social domain. This was concluded by Accenture on 2009, when only a 10 % of the companies actively modelled their supply chain carbon footprints and had implemented sustainability initiatives. And more than a third of supply chain executives have no awareness of the levels of supply chain emissions in their supply chain networks. (Hua, Cheng and Wang, 2011)

Knowing the two working branches to start improving the systems, this master thesis will be focused on the idea of improving the efficiency of an already in use system. More precisely, on the performance enhance of a set of two buildings located in the same plot. Most of the activities are carried out inside some kind of building, for that reason it was believed to be important to define how is energy used in an industrial building and how its efficiency could be improved.

Previous studies concluded that building energy use is an important matter as energy is one of the most critical resources used over the building lifetime. Moreover, the challenge includes the fact that the performance of a building and its whole life emissions are the result of a complex interrelation of factors that influence like climate conditions, design, construction, used materials, operation regimes and the decisions made at the end of life stage. being a key element making the best decisions in the early stages of the design. Thus can reduce the capital cost of integrating low environmental impact, recycled or innovative materials and therefore reduce overall life cycle emissions. (Rai *et al.*, 2011)

About the storage stage of production. The processes of delivering and storing use such a large amount of energy. This results in large amounts of carbon emissions from the transport and warehouse operations in the supply chain. Thus, the importance of studying and reducing the needless energy usage in that kind of asset. (Hua, Cheng and Wang, 2011)

When it comes to energy use distribution, previous studies concluded that regarding non-residential buildings, more than half of the electric energy use belongs to support processes (about a 54 %), whilst 46 % is accounted for production processes. Among the support processes, even though different studies differ in which of the support process is the most energy intensive, it’s clear that the ones with a greater importance when speaking about energy use are heating, lighting and ventilation processes. Thus revealing the importance of maintaining that systems and addressing the necessary effort to achieve more efficient and sustainable buildings (Fichtinger *et al.*, 2015; Paramonova and Thollander, 2016)

As an example of social policies regarding sustainable building upgrades, it’s explained the case of Sweden. During the years 2010-2014 it was revised a program to help small and medium companies to finance energy audits. This way, it was supposed to improve the investment in sustainable improvements in sectors whose priority to move to greener equipment was stuck due to the economic considerations and because of energy it may not be among the main prioritised costs for the companies. The results of that program were 713 participating companies and a net energy savings of 340 GWh/year (6 % of the total companies’ energy use). Moreover, it’s important to highlight that 53 % of the solutions included in the energy audits were implemented. The cost-effectiveness of the program is about 5.7 € per saved MWh and the energy saved per invested public money is 150 kWh/€. The conclusion of the Swedish program is that even if it’s not a solution to implement solitarily, it’s a good strategy to be implemented in conjunction with other programs in order to achieve the sustainability targets. (Paramonova and Thollander, 2016)

1.2 Energy in Sweden

According to the *Energy in Sweden 2017 report*, published by the *Swedish Energy Agency*, the energy use in Sweden can be divided in three different sectors: industrial, whose main carriers are biofuels and electricity; transport, whose main carrier are oil derived products like petrol, diesel or aviation fuel, but with an increasing incorporation of biofuels and electricity; finally, the residential and service sectors’ main carriers are district heating, electricity, oil products and biofuels.(Swedish Energy Agency, 2017)

Starting in the 70’s and continuing up to nowadays, the Swedish energy use tends to move to greener energy sources as biofuels and wind, by reducing at the same time the usage of fossil fuels (basically crude oil), and nuclear fuel (see Figure 1).

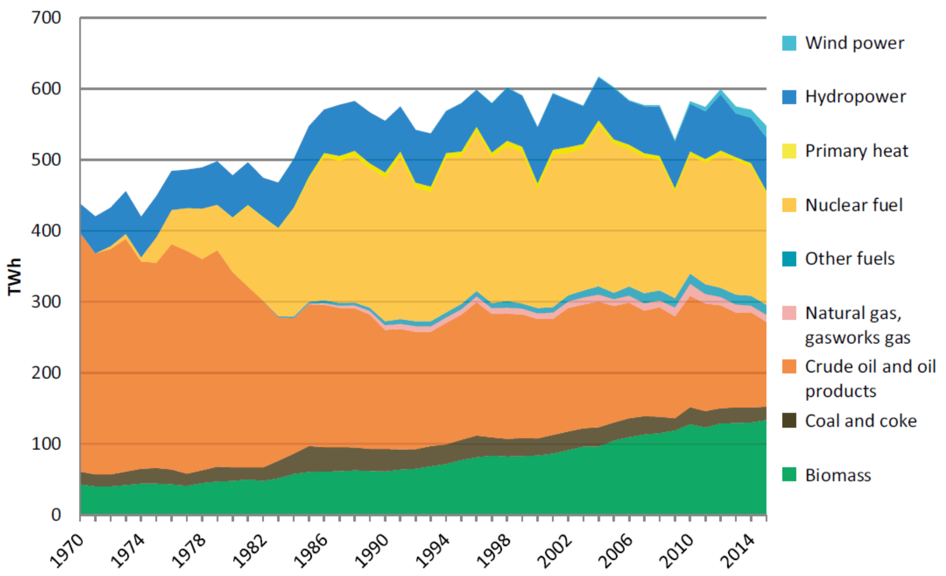

Figure 1: Total energy supply by energy commodity, TWh. Source: Swedish Energy Agency and Statistics Sweden.

The industrial sector has reduced its final energy use in 1 % from 2014 to 2015 (see Figure 2). Being that the last available data. The sector implies a 38 % of the Swedish total final energy use, from which a 40 % is sourced by biofuels, 35 % by electricity and about a 19 % is provided by fossil fuels.

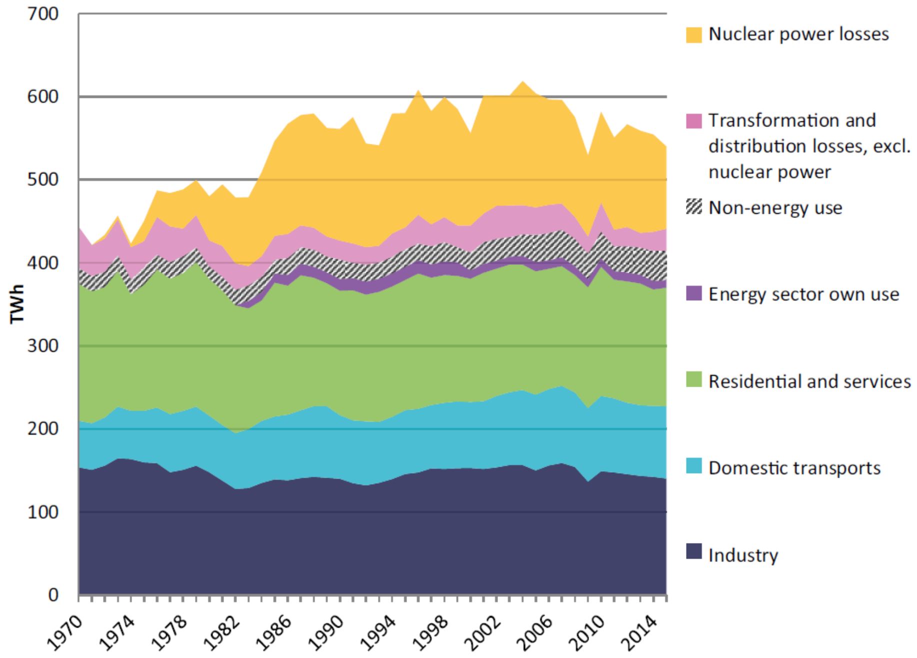

Figure 2: Total energy use by final use and loses, TWh. Source: Swedish Energy Agency and Statistics Sweden.

The transition to greener sources of energy accounts not only to the spreading environmental awareness but to the stability prices that those give to the users. Even though during the last years almost all the traditional energy sources have seen how their prices are reduced (despite of natural gas that increased its price in the period 2014-2015), their prices continue being quite higher in contrast with the wood chips used in industry, making them even more attractive for its use as an energy source in the industrial sector (see Figure 3).

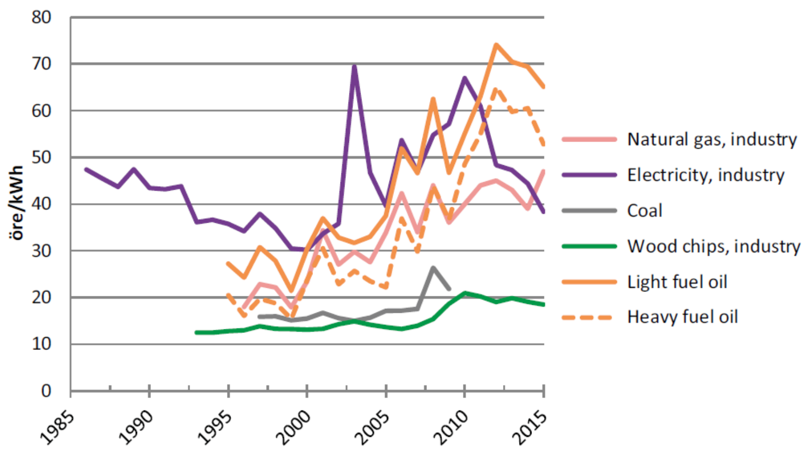

Figure 3: Energy prices for industrial customers, öre/kWh at current prices (2016).

Source: Swedish Energy Agency, SCB, European Commission (Oil Bulletin).

1.3 Literature review

This chapter of the report would try to justify the reason to choose such a topic, while highlighting the previous studies related to it. Moreover, it will reveal some details about the research method in order to give the reader an approach of how the previous work regarding the thesis was performed.

In order to develop the main body of the thesis and the literature review, the used research databases are *ScienceDirect*, *Scopus* and *Discovery*, the search tool of the Högskolan I Gävle. Some of the keywords used during the research were: climate targets, building renovation, energy efficiency, energy audit, Swedish energy upgrading, etc. Through these searches many peer reviewed articles were obtained that had to be read, selecting those more interesting for the project.

First of all, it's impossible to start any energy related research without pointing at the Paris Agreement, (UNFCCC, 2015) and the formulated targets by the European Countries for the 2020 and the 2030. Thus, in less than 12 years, the greenhouse gas emissions should be cut by at least 40 % from 1990 levels. At least 27 % of the energy share should be provided by renewable sources and the countries should improve by, at least, 27 % in energy efficiency. (European Commision, 2014)

Moreover, it's estimated that about a 5.5 % of the total GHG emissions are caused by the logistics and the transport sector. Accounting the logistics buildings for a 13 % of these emissions, so, being a significant source of GHG emissions that should be taken into consideration. (Fichtinger *et al.*, 2015) Another important issue in this area is the fact that the great differences among the supply chains of each company difficult the task of standardising the assessment, monitoring and management regarding GHG. (Rüdiger, Schön and Dobers, 2016)

Previous Energy audits were carried out in Europe revealing great potential of energy savings due to efficiency improvements. Not only with great investments, but with small or no addressed investments. Despite that fact, the paper of the government programs is still vitally important to motivate the study of its facilities and their derived enhancement. (Fresner *et al.*, 2017) not only among the small and medium enterprises (Paramonova and Thollander, 2016), but also among small investors like single-family and multi-family building' owners. (Nair, Azizi and Olofsson, 2017)

Among the solutions that have been studied, installed and resulted beneficial for the energy use reduction there are plenty of possibilities. From the envelope and the surface coating (Marino and Minichiello, 2015), improving the installed windows to those that fit better for the thermal and sunlight conditions (D'Agostino, Cuniberti and Bertoldi, 2017), studying the behaviour of the ventilation system in the building volume and reducing the thermal destratification (Wang and Li, 2017), its thermal behaviour (heating set points and heating schedules) (Jradi, Veje and Jørgensen, 2017) up to the improving lighting control strategy (Soori and Vishwas, 2013), being these just a tiny sample of the enhancing possibilities in all kind of buildings.

The undertaken literature review strengthened the awareness about energy use and how difficult it can be for the economic entities to promote the progress to more efficient infrastructures among the private sector. Thus reducing the total energy use and the human effect on the Earth ecosystems due to economic expansion. Although there is a vast literature focused on the energy efficiency issue, the topic is that broad that each studied system has its owns distinctiveness. Being useful to share any achieved knowledge to help future researchers, investors and citizens to get an easier way to make progress and make more profitable investments and enjoy a better environment conditions, respectively.

1.4 Aim and limitations

The main object of this thesis project is to develop an energy efficient solution for a company that needs to enhance its ventilation system. This project could resemble an energy audit but focused on the ventilation and comfort conditions issues, since the purpose of an energy audit is to define how energy is used in a company, building, process, etc. and try to minimize that unnecessary energy use in order to improve its efficiency while maintaining the required production rate.

Moreover, with the fact that the project belongs to a master thesis, it’s implicit the idea to put in practice the previous learned knowledge. Being a didactic way to approach to the work context and being a first experience in which the student carries out a professional project by itself, with the aid and guidelines of the supervisor who acts as it could be the project head in a company. This way, the student can experience the problems that could appear in an actual project and find and learn ways to solve them without that much guidance as in the previous projects developed in the degree courses.

About the project limitations, time is the main limit factor. Even though the project it’s been started within the timings stablished by the university, these are quite tight. For that reason, the survey will be focused on the study of the current ventilation system and its improvement.

1.5 Approach

The research strategy used in this thesis project was an action research: looking the system, trying to understand it in its whole context and designing the proper solution to be implemented. Moreover, the method followed in the survey correspond to that used in the energy audits.

1.6 Buildings description

The study developed within the thesis project is focused on a plot located in Sörby Urfjäll, an industrial park in the south part of Gävle (See Figure 4). The area houses companies working on different fields, from car dealerships, sports centres, production plants and other industrial related companies.

The plot is placed in the address Rälsgatan 2 (see Figure 5). About the surroundings, opposite to the studied plot the Swedish Railway Museum is located, an important attraction for the city due to the historic trains and other railway equipment that exhibits. In the same street, other companies like an IT company, a plumbing related company and a car dealership are located.

The plot includes an open area used to park the workers’ vehicles and to give the access to trucks as the companies belong to the industrial area.

The first Building, with two levels, hosts a cooking school. The first floor consists of the kitchen, that seize a big part of the surface; the washing room, holding the auxiliary equipment for the kitchen; the pantry, with all the foodstuff; a small dining area, in which 12 people can sit at the same time; a classroom, for 20 people; a teachers’ room, for four people; a small fika-room, for four people; the bistro, a bartender specialized classroom for 16 people; and two toilets. The second floor consists in two dressing rooms, each of them with a shower; two big classrooms, for 20 people; two small classrooms, for 12 people; three offices, one for four people and two individual ones; a big dining area, with space for 30 people; and two toilets (see Appendix M).

The second building is connected to the first one by means of a corridor that allows the transit without going outdoor. In this one is located the warehouse managed by DSV, a Danish transport and logistics company that offers transport services by road, air, sea and train. The main area of the building shapes the warehouse area but it also consists of a small part of offices for the management of the company, two dressing rooms, a big fika-room and two toilets. This equipment is placed in a double level part of the shed. The higher level hosts the ventilation system and the core server. The warehouse is divided in two areas by a central wall with three big apertures that allow the transport vehicles to transit through the warehouse and has six truck loading platforms that can work in parallel (see Appendix M).

The last building in the plot doesn't take part in the thesis study and it hosts a workshop.

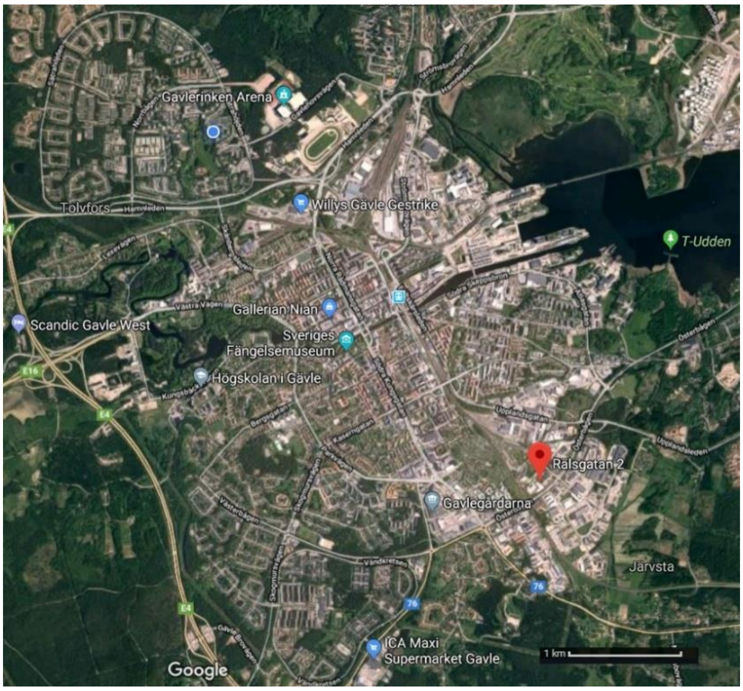

Figure 4: Location map of the plot in the city of Gävle. Source: Google Maps.

Figure 5: Access map of the plot. Source: Google Maps.

2 Theory

2.1 Energy auditing

An energy audit is a process in which a building, industry, process, company, etc. is analysed in terms of how and how much energy uses. Within this process, different energy inputs and end-users that are found in industries and buildings are surveyed and analysed, aiming to suggest energy efficient and conversion measures in order to improve the efficiency of the considered system and move to greener ways of energy supplying.

There are many accuracy levels when performing an energy audit, but there are some main points that are usually followed when carrying them out. The process often starts with a first meeting with the company in which the scope and the general lines are defined. Then the necessary measurements are taken both during the operating and non-operating hours, if needed with the purpose of shaping the distribution of energy use. Finally, different solutions, behavioural improvements and other tips are draft while defining the impact of their implementation in order to give the company a report with the improvement actions.

The audit can be divided in 3 different stages or levels during its development. The first level (Level I) entails the introductory analysis of the invoices and attainable information, planning low cost measures. During the second stage (level II), the audit focuses on separating the energy use according to process units and a deeper insight into the efficiency measures. Finally, the third stage (level III), lead to a precise analysis of the cost-effective energy saving measures and their economic and environmental effects, as well as the interactions that happen when implementing them and likely future scenarios. Depending on their scope, not all the energy audits have to perform all the three stages.

About the importance of going ahead with the energy audits; buildings are, nowadays, responsible for the 40 % of energy consumption and 36 % of CO_2 emissions in the EU. Furthermore, even though the new buildings tend to consume 3 to 5 l of heating oil per square meter per year, old ones' consumption situates in 25 l on average, reaching 60 l in extreme cases (Kamari, Corrao and Kirkegaard, 2017). This is emphasized with the fact that SMEs (small and medium sized enterprises) represent a high share of energy consumption in Europe, with a short term potential of 10-20 % savings and a total of 25 % potential savings, whereof 40 % could be harvested with measures that don't require any capital investment. (Fresner *et al.*, 2017)

There are two main problems when speaking about energy audits on SMEs: The financial barriers and the non-financial barriers. The financial barriers comprise the lack of capital availability along with the fact that in an 80 % of the SMEs, energy costs imply less than the 10 % of the total costs. With regard to non-financial barriers, limited in-house skills to identify the problem and carry out the efficiency projects stays as the main factor, added to the fact, as revealed by surveys performed in the United Kingdom, 52 % of the SMEs have no idea of how much their electricity and heat bills account for. (Fresner *et al.*, 2017)

In order to solve the previous explained problems, the EU (European Union) funded projects to develop efficient energy auditing methods. Thus making them more attractive for the SMEs and supposing a reached benefit for the environment, as well as a boost for technological and process innovation and giving relevant information in order to create exhaustive knowledge in such a wide and diverse issue as it can be the ways to enhance the efficiency of a company. (Fresner *et al.*, 2017)

2.2 Industrial ventilation

Industrial ventilation accounts for many different definitions: from the environmental engineer's view, IV (Industrial Ventilation) means the design and application of equipment to provide the necessary conditions for maintaining workers' efficiency, health and safety; from the industrial hygienist's view it means the control of emissions and exposures to hazardous environments. Finally, from the mechanical engineer's view it implies the control of the environment with air flows, as well as the replacement of contaminated air with clean fresh air.

The importance of IV lies on the fact that working in a space with bad ventilation qualities may suppose a risk for the workers. Thus, is important to maintain and adequate oxygen supply in the work, control the hazardous concentrations of toxic substances in the air and remove them before they enter the work place, remove unpleasant odours and control the comfort conditions. These measures ensure a proper workplace that makes workers reach their peak efficient working status.

About the several efficiency measures related to ventilation, the most spread ones are the study and set of the proper air flows with variable speed drives and time control, the regulation of the input temperatures, the implementation of heat recovery devices, etc. innovative studies work on the saving potential identification of a proper ventilation that effect a thermal destratification reaching a more effective way to maintain the optimal conditions in the workplace thus reducing up to 38 % energy saving in a standard warehouse. (Wang and Li, 2017)

2.3 Lighting

The lighting system in industrial environments comprises all the devices that help provide the proper light to the building and areas of interest. Thus, from the control devices that enable the lights to switch on/off in a manual or automatic way depending on the light conditions to the electric installation that connects the system and the luminaires that provide light to the different areas.

About the importance that lighting has on the company, it's fundamental in order to build a safe environment that permits the employees to work in the optimal conditions thus achieving peak efficient performances. For that reason, many studies have been performed in order to definite the ways lighting improves the performance on the workers. Furthermore, there are 10 reasons or mechanisms that have a main impact. (Juslén and Tenner, 2005) These may be summarized in the fact that a proper lighting causes an enhanced feeling with oneself, thus improving the self-confidence, it also improves the relations within the workers and so strengthening the built links and the cooperation among them, finally, it enhances the relation between the worker and the work place, creating a positive feeling on the worker about its job. These causes an improvement on the workers' performance that proved to be positive for the company's development.

When speaking about efficiency measures to improve the lighting in the companies, it is reported that, even though is quite difficult to have exact estimation of the savings produced by the improving of actual lighting with both new hardware (luminaires and lighting controls) and an enhanced use of the daylight due to the complex variety of factors that influence it, its average savings potential usually goes from 6-70 % of the energy use. (Soori and Vishwas, 2013)

2.4 Heat recovery

Heat Recovery Ventilation (HRV) defines the mechanical ventilation system that, by means of specific equipment, performs an exchange of heat between the inbound and outbound air flow, reducing thus the energy load related to ambient heating.

Air-to-air energy recovery systems may be classified due to their application: process-to-process, process-to-comfort- and comfort-to-comfort. Process-to-process devices are used to transport the surplus heat from a process to another process which has a lack of heat and whose characteristics make profitable the incoming heat. The process-to-process recovery is usually the one which recovers the maximum amount of energy. Process-to-comfort devices are used to transport the surplus heat from a process to the ventilation system and thus helping reach the comfort conditions during the cold periods. Process-to-comfort disadvantage regarding process-to-process recovery is basically the fact that the energy is only saved during the cold periods, being necessary to modulate the system during the year and, thus being more complex while saving less energy. Finally, comfort-to-comfort recovery devices are used to transport heat between the ventilation supply air and the exhaust airflows. They may work increasing the supply air temperature by reducing the exhaust air temperature or just the opposite cycle, depending on the weather conditions. Usually comfort-to-comfort devices work in a narrow range of temperatures among the streams, being important to have an accurate energy transfer models and choosing the appropriate exchange system so the system gets high efficiencies (ASHRAE, 2008).

The most important economic factors when deciding about implementing a HRV are: Life-Cycle Cost, system installed cost, energy cost, and proximity of supply to demand. In order to calculate properly the recovery implementation cost benefit, is better to consider all its life from its installation, operation, energy-saving costs, maintenance and disposal. Considering the effect that a properly designed system has on the energy savings, its required investment usually has a payback period of less than 5 years, achieving a payback period of 3 years in some cases. The system installed cost is usually reduced when installing the recovery device due to the fact that mechanical refrigeration and main heating equipment can be reduced in size as the exchanger absorbs part of the load. Energy costs are a decision factor when moving to new ventilation systems such as HRV. Absolute cost of energy and relative costs among different energy sources shapes the suitability of HRV. Thus, high energy costs or the relative high cost of traditional energy sources like oil are positive conditions to invest in systems like HRV. Last but not least, proximity of supply to demand is essential in this kind of systems, being more favourable those with a large central energy source and a nearby waste energy use rather than those with scattered waste energy sources and uses.

The most common air-to-air energy exchangers are the rotating energy wheel regenerator and the flat-plate recuperator (see Figure 6). Rotating energy wheel regenerator consists on a circular honeycomb matrix of heat-absorbing material that slowly rotates within the supply and exhaust air streams. As it rotates the head is picked from one of the streams in one half of the wheel and given up to the other stream in the other half of the wheel. Flat-plate recuperator consists in a framework supporting a number of thin plates spaced apart with air passages between them. The plates are normally of metal allowing only sensible heat transfer, but could be made of porous membranes allowing the latent heat to be exchanged. Besides the used device, the way the airflow goes through the device is an important characteristic to define its efficiency, being typically used the counter or crossed flows rather than of the parallel flow (see Figure 7).

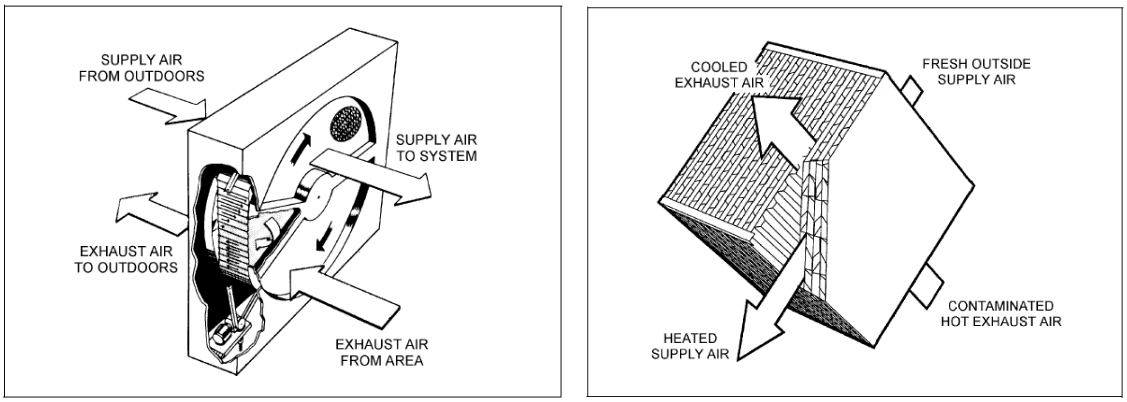

Figure 6: Rotary air-to-air energy exchanger (left) and fixed-plate cross-flow heat exchanger (right). Source: ASHRAE.

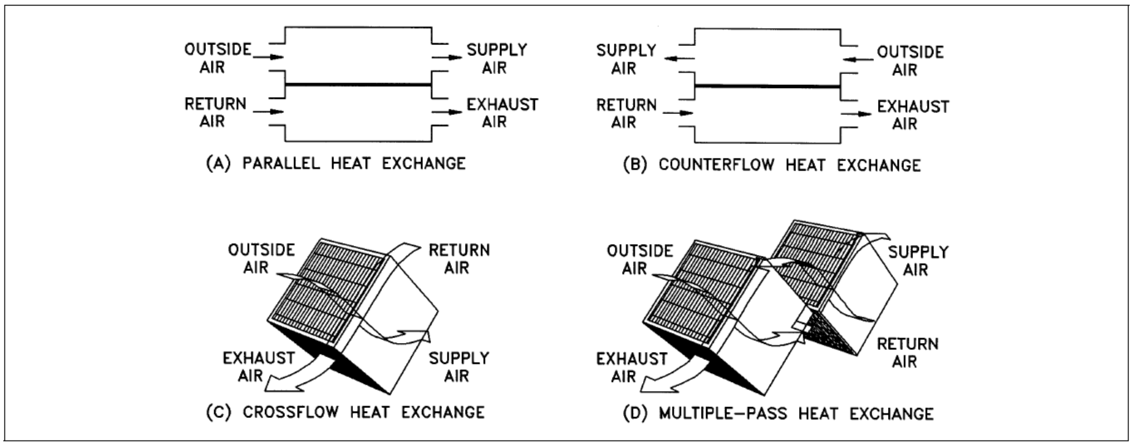

Figure 7: Heat exchanger airflow configurations. Source: ASHRAE.

3 Method

As previously explained, the thesis focuses on the enhancement of the ventilation system in a set of buildings placed in the same plot. For that reason, the research strategy that was chosen to follow during the development of the project was an action research (Biggam, 2015). Thus, treating the current ventilation system and the current conditions as a problem that needs to be understood better and to be solved. As an action research, the scheme to follow was to look, consecutively to think about what was observed and finally to act towards a better solution, and thus repeating the loop as the project was progressing (see Figure 8).

Figure 8: Strategy scheme.

Once the strategy was defined, the method to follow was chosen. In this case, the author designed a method based on the one followed in the study carried out by Johannes Fresner and its team (Fresner *et al.*, 2017). The followed approach consisted of 7+1 steps:

1. First, a meeting with the supervisor was held, in order to define in a basic way what the project scope would include.
2. Independent research on the energy audits topic was done in order to have a more extensive knowledge about the issue and be prepared for the meeting with the company.
3. A first meeting with the company delegate was held, in situ, in order to have a primary view of the location and what the company expected, which were the priorities and define the scope of the project.
4. Various visits to the studied buildings were necessary in order to take the necessary measurements, complement the previous information and define the buildings' characteristics in the proper accuracy.
5. At the same time, the data was collected and processed using MS Excel tool. Since that software allows to analyse it in an easy and quite graphic way.
6. The collected data was deeply analysed and used to design a proper solution that fulfil the company's expectation.
7. The report was finished and presented to the company giving a deep view on the problem and the solution.
8. The next point was not part of the scope of this educational project. But, in a non-educational energy audit, a follow up would conclude the project. Thus supporting the implementation of the selected measures and helping with the elements of energy management.

3.1 Measuring instruments

In order to take the needed measurements, three different devices were necessary: a thermo-anemometer was used to measure the air speed in the ventilation ducts and then estimate the airflow that was being channelled, a laser-meter to measure the lengths of the building and define the areas to plot the building drawings (see Figure 9) and a flow measuring device was used to obtain the flow of the supply outlets and exhaust hoods in the different spaces of the cooking school (see Figure 10).

Figure 9: Thermo-anemometer (left) and laser-meter (right) used in the study.

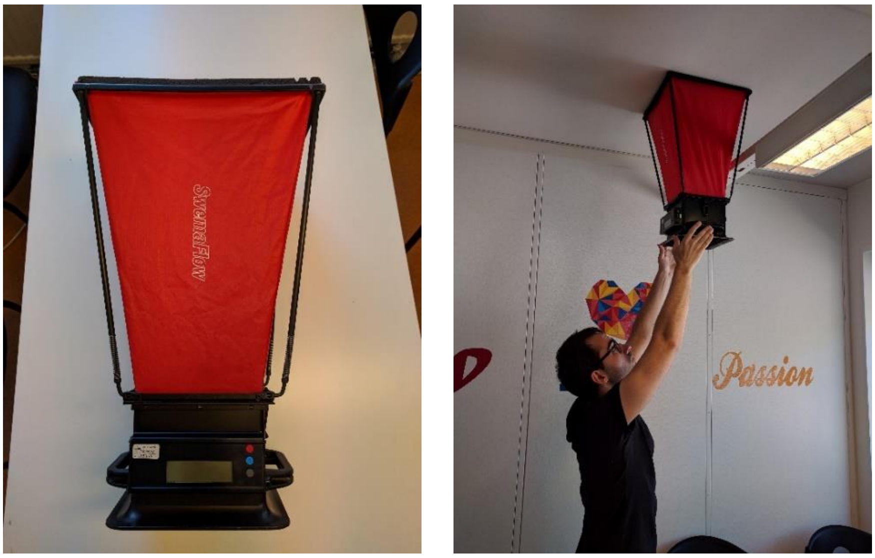

Figure 10: Flow measuring device (left) and an example of how to measure the flow in a ventilation outlet (right).

In order to take the measurements to define the current airflows delivered by each AHU, it was followed a simplification of the Log-Tchebycheff Rule defined by the *ASHRAE Standard 111* (Suppo *et al.*, 1988). Thus, air speed measurements in the ventilation ducts were taken following the quadrant guidelines of the circle shaped by the duct and the number of measurements required to calculate the average was defined according to the diameter of the ducts (see Figure 11).

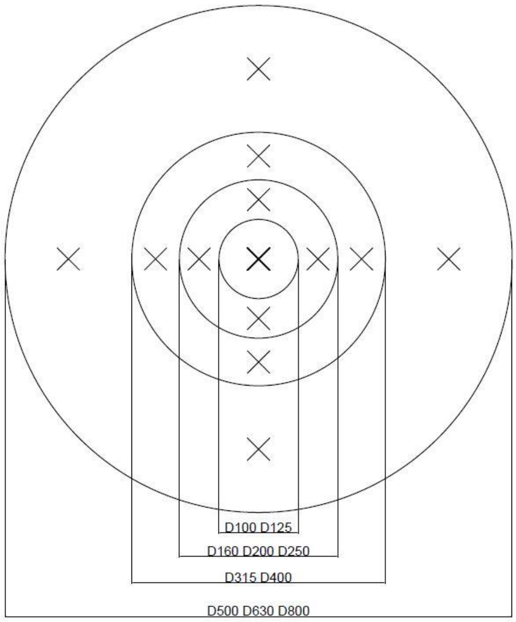

Figure 11: Used method to measure the air speed in the ducts.

Once the average air speed in the ducts was measured, the channelled airflow was obtained by the equation (1).

$$Q = V \cdot A \cdot 1000 \quad (1)$$

Where:

Q = airflow (l/s)

V = air speed (m/s)

A = duct area (m^2)

1000 = conversion factor (1000 l = 1 m^3)

3.2 Procedures

3.2.1 Data collection

Since the visiting schedules were quite restricted to the labour periods, the meetings with the manager had an extra value as he could provide important information like the ventilation system behaviour during the non-working period: for the AHU (air-handling unit) TF1 the working period starts at 6 am until 1 am, 7 days a week; the AHU TF4 works the same period as that of TF1, but just 5 days a week; for the AHU TF2 and TF3, the working period starts at 6am until 6pm, 5 days a week. The set target temperatures are 18 °C for the warehousing area and 21 °C for the offices, classrooms and other-use spaces. Moreover, the manager also defined the serving rooms for the AHU placed in the cooking school (TF4). TF4 delivers ventilation flow to the whole building but the kitchen and the washing room that have a specific dedicated AHU.

The other AHUs have exposed ducts, which eased the delivery definition for each of them. The three AHU are placed together in the second level of the warehouse building (see Appendix M). TF1 delivers ventilation airflow to the offices, fika room, toilets and dressing rooms in the warehouse building. TF2 delivers ventilation airflow to the central area of the warehouse and TF3 delivers airflow to the back part of the warehouse.

Observations during the visits and the information given by the manager and the teachers that work in the cooking school made possible to define the operative hours of each class and the average occupancy (see Appendix C).

Finally, the visits were used to take the measurements that would be used to define the building drawings, necessary to design the new exhaust air ducts in the warehouse building.

3.2.2 MS Excel

MS Excel was chosen as calculus tool due its easiness to work with and the graphical results that it provides. Thus, it was used to obtain the current airflows, to design the optimal ones in order to select the proper AHUs to install and to obtain the savings derived of the solutions.

3.2.3 AutoCAD

The software AutoCAD was chosen to plot the drawings, being the most extended tool when sketching building elements. The building drawing gave a better perspective to the current situation in order to ease the task of thinking and designing the final solution.

3.2.4 Airflow optimisation

Even though the previous performed measurement of the current delivered airflows in each of the areas, the visits to the company and the visual observation of the system caused to suspect that they were not working in the proper conditions. For that reason, that measurements were taken as an approach number but not as decisive for the new solution. Thus, the main literature to design the appropriate airflows was the ASHRAE standard (see Appendix D). At first, the airflow requirement for each different space (Hedrick *et al.*, 2015) were taken into consideration to find a close value. But, having in mind that these standards are quite generic and following the expertise of the professional in ventilation systems, it was decided to increase those values to ones that warranted the comfort conditions in the occupied areas (see Appendix D).

3.2.5 Ventilation duct design

In order to design the exhaust duct system, the channel pressure drop diagram was taken into consideration (see Appendix F). Thus, the requirements that the ducts had to accomplish were the suitability to channel the required airflow, in order to provide to each area, the proper amount of fresh air, and a pressure drop in all the circuit with values close to 1 Pa/m, warranting low losses in the system.

About the placing of the exhaust hoods, it was considered to separate them as much as possible from the supply outlets. Giving a significant space among them so the airflows doesn’t affect each other and so, fulfilling the ventilation requirements.

3.2.6 Building occupancy survey

In order to have a more complete perspective of the building and the activities performed there, a survey was carried out among the employees that work there. Thus, the occupancies of the classrooms, offices and common areas were obtained.

The ventilation system behaviour and the set temperature targets were obtained through the company manager. This way it was possible to pair the occupancy hours with the ventilation system working periods and try to find a proper configuration that ensures the comfort conditions while optimising the energy use.

3.3 Current situation

The warehouse building uses three different AHU to provide the ventilation for all the spaces. The AHU that provides the offices and the non-warehousing purposes rooms is a basic model with no energy recovery system. In the current situation, the system delivers 500 l/s to its service areas (see Appendix B). Moreover, this part of the building has an exhaust air system, expecting to be a balanced ventilation system. The problem observed during the visits is that, due to the bad design of the system, the power of the supply system is quite greater than the power of the exhaust system. That situation creates an undesired overpressure in the rooms, producing an increase in the moisture absorbed by the walls.

The AHUs that deliver the make-up air to the warehousing areas have a recirculation system, thus reintroducing to the building air coming from the inside and thus, reducing the necessary heat during the cold periods, but currently not working in the proper conditions. In both systems the channelling of the air is exposed, being easy to study and define how and where each of the systems deliver. The unit that works on the central area in standard situation provides an airflow of about 560 l/s. The one that delivers fresh air to the back part, even though is the most extensive area, it delivers only 380 l/s (see Appendix B). this low airflow, in addition with the observation of some damages on the ducts that deliver air to the back area of the warehouse raised the question that the system could be not working on the conditions that was designed to.

The building is connected to the DH (district heating) grid, thus using it when needed. This way, the heating system differs between the two buildings. In the warehousing building all the AHU are connected to the DH through a heat exchanger that heats the supply air to the set value. Moreover, an air-curtain is placed in front of each truck platform and turned on when needed in order to preserve the comfort conditions. Finally, extra fans are placed in the ceiling, also provided with a heat exchanger connected to the DH thus helping reach the comfort conditions in the area.

In the cooking school building, the AHU is also connected to the DH system through a heat exchanger that increases the supply air temperature during the cold periods. Moreover, the building has a set of radiators distributed by the rooms that help reaching the comfort conditions in the areas. Even though it was not possible to measure the outbound airflow from the AHU, there was carried out an airflow study in the building. Measuring the inbound airflows providing from the supply ducts and the outbound airflows to the exhaust outlets it was possible to determine the flows in each room and the balance. (See 4.1 The cooking school building).

4 Results

4.1 The cooking school building

The cooking school building has already implemented a ventilation system with supply and exhaust airflows. Thus, there was no need in designing a new supply and exhaust duct system. The main problem in that building was the users' dissatisfaction regarding the comfort conditions in the building. The airflow measurement carried out in the different spaces of the building revealed that the current ventilation doesn't have enough power to fulfil the ventilations of all the rooms in the building. Furthermore, the current system is unbalanced. Resulting in an overpressure conditions that are negative for the building, driving the moisture into the walls (see Table 1). Thus, the data analysis was focused on the finding of the airflow load that the AHU should deliver. As previously explained, the airflow requirements for the different purposes areas were increased as recommended by the ventilation professional regarding those defined by the ASHRAE. The values used in this project were 15 l/s, person for the office rooms. This value was also used for the dining areas. For the dining room in the first floor, even though it has space for 30 people, the used occupancy value was reduced to 20 people taking into consideration the fact that this diner area has a more sporadic occupancy, so a lower airflow could maintain the comfort conditions. The considered values for the classrooms were 7 l/s, person added to 0.35 l/s, m^2. The resulting airflow load to deliver by the AHU in the cooking school building is 1568 l/s. (see Table 1).

Table 1: Airflow load requirement in the cooking school building (TF4).

	Area (m^2)	**Occupants**	**Required airflow**
Budapest	11.40	4	60
Paris	16.63	4	60
Stockholm	22.33	20	148
Dining area GF	10.93	12	180
Pantry	22.56	1	15
Bistro	27.55	16	122
WC men	1.80	1	15
WC ladies	1.80	1	15
(London)Big classroom	54.90	20	159
Dressing men	11.16	1	15
Dressing ladies	16.72	1	15
WC men	1.80	1	15
WC ladies	1.80	1	15
Dining room 1F	37.73	(30) 20	300
Roma	44.00	20	155
Beijing	32.60	12	95
Boston	28.03	12	94
Seattle	16.07	4	60
Berlin	11.97	1	15
Barcelona	11.97	1	15
		Total (l/s)	1568

In order to fulfil the building requirements, the compact AHU produced by the company *Fläktwoods* were chosen (see Appendix H). For the cooking school building the selected model was the EQ PRIME 014 with rotating heat exchanger. The type of the heat exchanger was chosen thinking that the environment in the offices and classrooms is quite clean, so it was proper to implement a rotating heat exchanger and its efficiency is greater than in a cross flow plate exchanger.

As a complementary part of the project, the ventilation schedules were revised. Even though the company was occupied only from approximately 8 am to 8 pm at maximum and only during the weekdays, the ventilation system works from 6 am to 1 am without any pause, also only on weekdays. For that reason, it was decided to reschedule them so the ventilation working period starts at 7 am until 8 pm, on weekdays. Even though it could happen that occasionally the last workers were still in the building but close to its departure, the thermal inertia would help maintain the comfort conditions.

4.2 The warehouse building

In order to study the warehouse building, it was decided to study two different scenarios. In one of them the new system would be an enhancement of the current one. Thus, the designed system would consist in three different AHU, one for each area (offices, central space and back space). In the second scenario, the AHU assigned to provide fresh air to the warehousing areas would be combined in only one unit that provide the air to both spaces.

In both studies, it was followed the same approach as that in the cooking school. In that case, the used airflow requirements were 15 l/s, person for the offices and the fika room and 7 l/s, person added to 0.35 l/s, m^2 for the warehousing areas. (see Table 2, Table 3 and Table 4).

Table 2: Airflow load requirement in the warehouse offices area (TF1).

	Area (m^2)	**Occupants**	**Required airflow (l/s)**
Office 1	34.90	2	30
Office 2	12.33	4	60
Office 3	24.24	4	60
Printer room	12.54	1	15
Corridor entrance	9.49	1	15
Fika room	26.71	3	45
corridor fika	11.89	1	15
WC men	22.26	2	30
WC ladies	22.26	2	30
		Total (l/s)	300

Table 3: Airflow load requirement in the central warehousing space (TF2).

	Area (m^2)	**Occupants**	**Required airflow (l/s)**
central space	852.30	6	340.30

Table 4: Airflow load requirement in the back warehousing space (TF3).

	Area (m^2)	Occupants	Required airflow (l/s)
central space	1667.60	3	604.66

In order to fulfil the requirements of the offices in the warehouse building, the chosen AHU was the EQ TOP 005 with rotating heat exchanger. As it was a clean area with relatively little demand of fresh air, it was decided to install the model TOP due to its easiness to install it, being a smaller unit, and that has the option to be implemented with a rotating exchanger that increases its recovery efficiency.

In order to achieve a completely functional system, it would be also necessary to connect the exhaust ducts that are currently connected to the roof through an independent fan, to the new unit. This could be done with a linear section of ducts. (see Appendix M).

Furthermore, due to the result of the occupancy study, the suggested working period for the AHU that delivers to the warehouse offices is from 8 am to 6 pm, only working during the weekdays. Being this one the zone with the highest savings derived of the new scheduling, coming from a working period that started a 6 am and stopped at 1 am during the full week.

In both the proposed scenarios to improve the warehouse ventilation, the schedules were improved from a current starting time at 6 am and finishing time at 6 pm, working only the weekdays; to a new schedule that starts at 7 am until 6 pm, also only the weekdays.

4.2.1 Scenario I – three AHU, one for each area

With that conditions, to fulfil the requirements in the central area, it would be necessary to find a proper device to provide 340 l/s to the space. For that reason, it was chosen the model EQ PRIME 005 with plate heat exchanger, as the dusty environment of the space doesn't permit to install a rotating heat exchanger.

Moreover, as the previous system was a recirculating unit and the recirculated air was taken directly from the AHU, there was no exhaust air piping system. For that reason, it was decided to design an exhaust duct system that crosses the space through its central section. Being this way as far as possible from the supply outlets and thus reducing the negative effect on the space ventilation (see Appendix M).

For the back area, it was chosen the model EQ PRIME 008 with plate heat exchanger, thus achieving the necessary 605 l/s that the space requires. The exhaust duct system in this space was designed the same way that in the central area. Crossing the central section of the warehouse and alternating the supply outlets and the exhaust hoods in order to separate them as much as possible.

As complementary point in order to achieve optimal conditions in this area, some damages in the duct system that provides air to the area were observed during the visits. For that reason, a small maintenance work would be recommended so the new system works in the proper conditions.

4.2.2 Scenario II, one AHU for the central and back areas

Scenario II consists in the combination of the labour that is currently performed by two different units in only one unit. The pros of this scenario are a simpler solution as only one unit would be installed, instead of two. But, an extra change in the supply duct system would be necessary in order to connect both areas to only one unit. Moreover, in case that the unit malfunctions, the affected area would be bigger.

In order to fulfil the requirements, the chosen unit is the model EQ PRIME 008 with an extra-big fan option and a plate heat exchanger, able to provide the required 945 l/s.

In this scenario, there would be also only one exhaust duct system that would channel the outbound air. In this case it would consist in a duct crossing the warehouse from in all its lengths by the central section, to locate the exhaust hoods as separate as possible from the supply outlets (see Appendix M).

4.3 Economic study of the solutions.

For the economic study only the first scenario was included as the installed power in both cases was nearly the same and the savings were slightly higher in the scenario II. For that reason, the economic study was performed taking the less optimistic of the cases.

Thus, the studied solutions were the implementation of the new AHUs with the energy recovery technology and the reduction of the ventilation working hours. Even though at the beginning of the project it was also in mind the renovation of the temperature targets set in the ventilation system, they were already 21 °C for the offices and 18 °C for the warehousing spaces. For that reason, it was decided not to reduce them more in order to achieve a proper comfort conditions.

The result of the solutions economic study is not a cost value but a limit value that the company should pay in order to get benefits of the investment in a 15 years and a 3 years' horizons. In order to calculate the savings derived of the investment, it was taken into account the saved heat energy through the heat exchangers and the saved electricity derived from the restated ventilation working periods. As the ventilation system has to serve the same area than the actual one and the time was a restricting factor, it was assumed that the power of the installed ventilation system and the current one are the same, thus not including the savings derived from the higher efficiency of the new system (see Table 5).

Table 5: Yearly savings derived of the implementation of the project solutions.

	Saved heat energy (MWh)		**Saved electricity (kWh)**
TF1	26		2 590
TF2	9		156
TF3	16		240
TF4	98		2 232
TOTAL HEAT	150		5 218

Energy price (SEK/MWh)	748.86	**Energy price (SEK/kWh)**	1.08
SEK	112 495	**SEK**	5 624
	TOTAL SAVINGS (SEK)	118 119	

To calculate the limit investment cost it was used the net present value system. To do that, it was assumed that the discount rate for the company was 6 %. Moreover, it was stablished two different investment horizons, one of 15 years in case that the company was really into investing in the new ventilation system, and another one of 3 years, intending to simulate a company whose priorities are not the ventilation system investment. With that data it was calculated the current value of the savings derived of the inversion in those years following the table that gives the factor to update the investment value (see Appendix K) and equation (2).

$$N = S \cdot n_f \quad (2)$$

Where:

N = Updated value of the savings (SEK)

S = Savings produced each year (SEK), assuming that they are constant

n_f = Updating factor, depends on the discount rate (r) and the investment horizon years.

This way, the limit cost of the investment to recover it in 15 years is of 1 147 176 SEK. Otherwise, in case that the company would want to take the investment back in less than 3 years, the maximum cost that they would pay would be 315 378 SEK.

5 Discussion

This chapter will provide a critical evaluation of the performed project aiming to summarize its main goals and, also, the weak points of its performance.

The original aim of the thesis project, as explained in the initial chapters of the report, was to develop an energy audit developed in the warehouse building placed in the plot. Due to the restricting time, this target evolved through a more specific study focused only in the ventilation. In exchange, a second building (the cooking school) was added to the study.

As part of an energy audit first, or a ventilation study later, the main implicit aim was to increase the efficiency of the studied system. Thus, helping also to move forward to reach the proposed European energy targets by 2030. Regarding the efficiency increase, the new ventilation working schedules reduced in 30 % in average the working hours for the different AHU. Moreover, the implementation of the heat exchangers resulted in a heat demand reduction of about 67 % compared to the system without heat recovery. Quite good values to motivate the investment.

Even though it's said that logistics and warehousing activities are a significant source of GHG emissions (Fichtinger *et al.*, 2015), the studied buildings could be classified as low GHG sources, assuming that the used electricity comes from green sources and district heating as a green source. Even that, the truck traffic derived from the warehousing activity could be considered its outcome, so increasing the GHG emissions derived of the buildings.

It was said in the introduction that more than 50 % of the energy use in the non-residential building was accounted by the support processes, being those main users the heating, lighting and ventilation systems (Fichtinger *et al.*, 2015; Paramonova and Thollander, 2016). Although more specific measurements would have been necessary to perform accurate statements about the issue, it was easy to say that the studied set of buildings was one of these cases, being those support processes the main energy users.

Another important statement that was verified during the course of the project was that taking the proper decisions in the early stages of the project, when it's still a design concept, saves money in the later stages of the project. Thus a proper ventilation system would help to reduce the energy demand and the derived costs in a future time.

Finally, the most important aspect of the performed study is that even though the project was not fully implemented, just the release of this report is already helping spread the importance of the efficiency enhancing projects and by doing so, reducing the reluctance to perform those studies and contributing to the faster progress to a more sustainable world.

6 Conclusions

The project consisted in the study of the ventilation system in the set of buildings placed in Rälsgatan 2-4, Gävle. Concluding with an effective solution that reduces significantly, up to 67 %, the heat demand for heating spaces, thereby reducing the derived costs, that could be implemented and repaid in a short period of time.

Furthermore, the suggested rescheduling of the ventilation system constitutes an easy way to reduce by 30 % the derived electric demand. Thus being a solution that doesn't require any investment. So, a cheap way to start moving towards a more efficient, green and competitive development of the company.

6.1 Outlook

The performed study, as thesis project, is identified by the tight scheduling that supposes. For that reason, some studies that would be carried out in a more accurate way, were performed in a simplified method and some assumptions were taken into account in order to reduce the performing time. Even though, that simplification doesn't interfere in the reliability of the study, thereby serving as a base for the implementation of the new ventilation system and as a basic energy audit of the company.

In that way, coming studies could include a more accurate temperature tracking in the inside and the outside of the buildings. Another suggested solution to study would be the enhancement of the windows, since the current ones are quite old and consist in an only pane thus implying high heat losses. A replacement of the lighting system would also be recommended, as the market offers much more effective solutions that could reduce the derived electricity demand, such as new led luminaires and presence sensors in those areas with low occupancy. Finally, the implementation of a PV system could result beneficial for the company.

6.2 Perspectives

Nowadays, environmental impact and sustainability are important subjects to take into consideration. This is because of the needed immediacy and collaboration that the topic requires, being something that can only be achieved by means of small gestures that add up which result in great changes. Thus, this project is one way to contribute to achieve a more sustainable world.

The analysis of the current systems and the design of the optimal solution that provides also a more efficient ventilation system, it was a small success to promote sustainable industrialisation. Furthermore, reducing the ventilation system energy use was a way to reduce the impact of the company and, hence, the impact of the city to the environment. Finally, the rescheduling of the ventilation working hours turned to be a primary practice to move towards a responsible production.

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8 Appendix

Appendix A Measured airflows in the cooking school

Table 6: Calculated required supply stream, and measured supply and exhaust airflows. The last column shows the balance between the measured streams.

	Required supply (l/s)	Supply (l/s)	exhaust (l/s)	Balance (l/s)
Budapest	60.0	8.6	2	6.6
Paris	60.0	12.8	8.5	4.3
Stockholm	147.8	23.2	8.6	14.6
Dining area GF	180.0	58.7	12.5	46.2
Pantry	15.0	153	15	138
Bistro	121.6	17.4	8.1	9.3
WC men	15.0	0	0	0
WC ladies	15.0	0	2.5	-2.5
(London)Big classroom	159.2	129.3	22	107.3
Dressing men	15.0	20.1	0	20.1
Dressing ladies	15.0	36.7	0	36.7
WC men	15.0	0	5	-5
WC ladies	15.0	0	0	0
Dining room 1F	300	85.2	49.2	36.05
Roma	155.4	108.9	15.3	93.6
Beijing	95.4	41.5	6.8	34.7
Boston	93.8	106.7	10.4	96.3
Seattle	60.0	45.7	0	45.7
Berlin	15.0	35	0	35
Barcelona	15.0	57.3	0	57.3
Totals (l/s)	1 568.29	940.1	165.9	

Appendix B Airflow measurements in the warehouse's AHU

For the AHU TF1, the one delivering the air to the warehouse offices, there were taken two different complete measurements. On one hand, the measurement of the duct just at the junction with the AHU, and further measurements in the two branches in which was divided.

Table 7: Calculation of the airflows delivered by the AHUs with the average speeds.

	Comments	Diameter (mm)	Area (m^2)	V (m/s)	Flow (l/s)	Total (l/s)
TF1						
M1	Near AHU, total flow	400	0.13	3.89	488.83	488.83
M2	right branch	250	0.05	3.06	150.21	
M3	left branch	315	0.08	4.52	352.25	502.46
TF2	Total	500	0.20	2.87	563.52	
TF3	Total	500	0.20	1.94	380.92	

Appendix C Classrooms occupancy table

Table 8: Occupancy and operative hours of the classrooms.

Classroom name	Occupancy	Active period
Budapest	4	8 h/day – 5 days/week
Paris	4	8 h/day – 5 days/week
Stockholm	20	8 h/day – 5 days/week
Bistro	16	8 h/day – 3 days/week
London	20	6 h/day – 5 days/week
Roma	20	6 h/day – 5 days/week
Beijing	12	6 h/day – 5 days/week
Boston	12	6 h/day – 5 days/week

Appendix D Airflow requirements

According to the ASHRAE, the airflow requirements that were needed for the study are summarized on the next table (see Table 9). In the table appear the values in combined form, taking only into account the occupancy of the spaces, and the separate form that depends on the area of the space and its occupancy.

Table 9: Airflow requirements according to ASHRAE in the combined and separate form. Source: ASHRAE (Hedrick et al., 2015).

	Combined form		Separate form	
Classrooms	4.3	l/(s·person)	3.8	l/(s·person)
			0.3	l/(s·m²)
Offices	8.5	l/(s·person)	2.5	l/(s·person)
			0.3	l/(s·m²)
Breakrooms	3.5	l/(s·person)	2.5	l/(s·person)
			0.6	l/(s·m²)
Pantry	17.5	l/(s·person)	2.5	l/(s·person)
			0.3	l/(s·m²)
Warehouses	10	l/(s·person)	5	l/(s·person)
			0.3	l/(s·m²)

The increased simplified requirements that were recommended by the professional are summarized in the table below (see Table 10).

Table 10: Airflow requirements according to the expert in the combined and separate form. Source: Roland Forsberg.

Offices	15	l/(s·person)
warehouse areas, classrooms and other-use spaces	7	l/(s·person)
	0.35	l/(s·m²)

Appendix E Gävle average temperatures

Table 11: Monthly average temperatures in Gävle.

Meteorologi och klimatologi 7:1

Temperatur och relativ fuktighet

Normaltemperatur i °C för månaderna och året, 1931−1960

Källa: Klimatdata för Sverige, Statens Institut för Byggnadsforskning

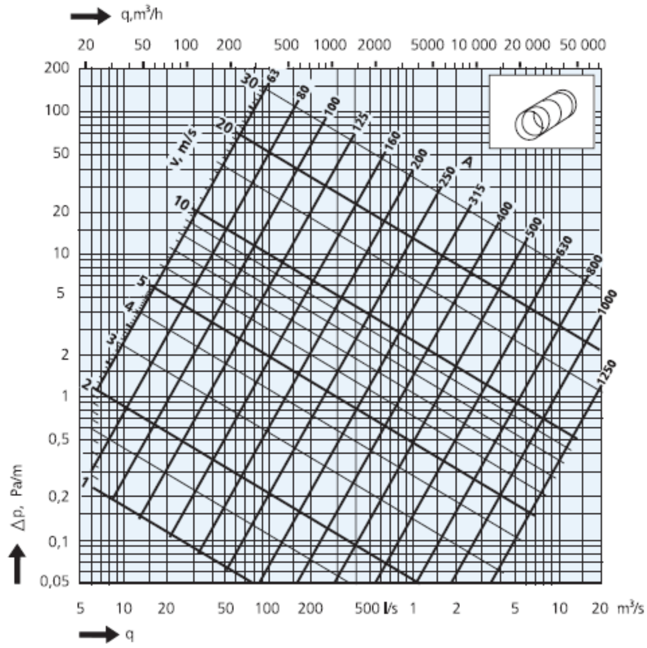
Station	Året	Jan	Feb	Mar	Apr	Maj	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Malmberget	0,2	−10,4	−10,5	−7,1	−1,9	4,0	10,2	13,9	11,5	6,0	−0,4	−5,2	−8,0
Karesuando	−1,5	−13,8	−13,9	−9,9	−3,6	3,0	9,8	13,7	11,2	5,4	−1,6	−7,3	−11,2
Kiruna	−1,2	−12,2	−12,4	−8,9	−3,5	2,7	9,2	12,9	10,5	5,1	−1,5	−6,8	−10,1
Pajala	−0,1	−13,1	−12,6	−7,9	−1,4	5,2	11,4	15,0	12,3	6,6	−0,5	−6,0	−9,8
Stensele	0,7	−12,2	−11,0	−6,8	−0,2	5,9	11,0	14,3	12,2	7,1	1,0	−4,2	−8,3
Luleå flygplats	2,0	−10,0	−10,2	−6,5	−0,5	6,1	12,1	16,0	14,0	9,0	2,5	−2,6	−6,5
Haparanda	1,6	−10,6	−10,9	−7,4	−0,9	5,8	12,3	16,3	14,0	8,4	2,1	−2,7	−6,8
Nordmaling	3,0	−8,2	−7,7	−4,3	1,1	6,8	11,7	15,4	14,0	9,3	3,3	−1,0	−4,4
Hällnäs	1,3	−11,8	−10,7	−6,3	0,1	6,7	12,0	15,4	13,3	7,8	1,0	−3,9	−8,1
Umeå	3,4	−7,8	−7,7	−4,4	1,3	7,5	12,7	16,3	14,6	9,5	3,5	−0,9	−4,3
[illegible]ffer	2,8	−10,2	−8,7	−4,2	2,1	8,1	13,0	16,0	14,1	9,1	2,7	−2,3	−6,4
Härnösand	4,4	−6,2	−5,8	−2,8	2,2	7,8	12,7	16,3	15,0	10,4	4,9	0,7	−2,7
Sundsvalls flygplats	3,9	−6,9	−6,3	−3,0	2,1	7,5	12,7	15,8	14,5	9,9	4,3	0,0	−3,4
Söderhamn F 15	4,7	−5,4	−5,2	−2,2	2,9	8,1	13,1	16,2	15,0	10,4	5,0	0,6	−2,4
Eggegrund	5,5	−2,9	−3,6	−1,9	2,1	6,6	12,0	16,0	15,8	11,8	6,9	2,8	0,1
Gävle	5,0	−5,1	−4,9	−2,2	3,3	8,7	13,8	16,6	15,3	10,7	5,3	0,9	−2,1
Frösön F 4	2,9	−7,9	−6,8	−3,5	1,5	7,0	11,4	14,5	13,0	8,4	3,0	−1,4	−4,5
Björkedet	1,3	−9,3	−8,5	−5,5	−0,4	4,8	9,4	12,6	11,1	7,0	2,1	−2,1	−5,6
Gisselås	1,2	−11,2	−9,7	−6,0	0,4	6,5	11,2	14,2	12,0	7,1	1,1	−3,8	−7,6
Östersund	2,7	−8,5	−7,5	−4,3	1,1	6,8	11,3	14,5	13,1	8,6	3,2	−1,1	−4,7
Sveg	2,1	−10,3	−8,6	−4,6	1,5	7,5	11,9	14,6	12,7	7,9	2,2	−2,9	−6,9
Rommehed	4,6	−6,2	−5,7	−2,4	3,2	9,2	13,6	15,2	14,5	10,0	4,8	0,3	−2,9
Edsbyn	3,9	−7,2	−6,4	−2,8	2,9	8,7	13,2	15,8	14,1	9,3	3,8	−0,7	−4,2
Mora	3,5	−8,5	−7,7	−3,6	2,8	9,0	13,3	15,7	13,8	9,1	3,7	−1,1	−4,9
Malung	2,9	−8,9	−7,8	−4,0	2,0	8,2	12,5	15,0	13,2	8,5	3,2	−1,7	−5,4
Falun	4,6	−7,0	−6,3	−2,6	3,4	9,7	14,1	16,7	14,9	10,1	4,8	0,4	−3,4
Västerås F 1	5,9	−4,1	−4,1	−1,4	4,1	10,1	14,6	17,2	15,8	11,3	6,3	1,9	−1,0
Uppsala	5,7	−4,4	−4,5	−1,7	3,9	9,9	14,4	17,2	15,8	11,2	5,9	1,6	−1,3
Norrtälje	5,9	−3,5	−3,8	−1,4	3,7	9,0	13,9	17,0	16,0	11,7	6,5	2,3	−0,7
Bromma flygplats	6,3	−3,5	−3,8	−1,2	4,2	10,0	14,7	17,6	16,4	12,0	6,8	2,5	−0,4
Stockholm	6,6	−2,9	−3,1	−0,7	4,4	10,1	14,9	17,8	16,6	12,2	7,1	2,8	0,1
Örebro	5,9	−4,0	−3,9	−1,0	4,5	10,4	14,6	17,1	15,6	11,1	6,0	1,7	−1,0
Nyköping	6,2	−3,3	−3,5	−0,8	−4,3	9,7	14,4	17,1	16,1	11,8	6,6	2,4	−0,4
Norrköping	6,9	−3,0	−3,1	−0,3	5,2	10,9	15,6	18,3	17,0	12,4	7,2	2,8	0,0
Motala	6,4	−2,8	−3,2	−0,7	4,6	10,1	14,5	17,0	16,0	11,9	6,9	2,7	0,0
Linköping	6,8	−2,9	−3,0	−0,1	5,3	11,0	15,4	17,7	16,4	12,2	7,1	2,7	0,0
Karlstad flygplats	5,9	−4,3	−4,1	−1,1	4,2	10,1	14,4	17,1	15,9	11,5	6,4	2,2	−0,9
Åmål	6,1	−3,7	−3,7	−0,7	4,5	10,2	14,5	16,9	15,6	11,3	6,3	2,2	−0,6
Vänersborg	6,6	−2,6	−2,8	−0,5	4,5	10,1	14,3	16,7	16,0	12,1	7,4	3,2	0,5
Skara	5,8	−3,3	−3,6	−1,1	4,7	10,2	14,3	16,5	15,2	11,0	6,3	2,3	−0,5
Strömstad	6,6	−2,9	−3,0	−0,1	4,8	10,5	14,4	16,9	16,0	12,1	7,3	2,9	0,0
Göteborg	7,9	−0,9	−1,2	1,3	6,0	11,5	15,2	17,5	16,8	13,1	8,6	4,5	1,8
Halmstad F 14	7,2	−1,6	−1,7	0,7	5,4	10,7	14,6	16,7	16,0	12,6	8,0	3,9	1,1
Kalmar F 12	7,0	−1,7	−1,9	0,0	5,1	9,8	14,5	17,2	16,3	12,3	7,6	3,6	0,9
Västervik	6,9	−2,0	−2,2	0,0	4,8	9,7	14,6	17,4	16,4	12,3	7,6	3,5	0,8
Visby	7,2	−0,6	−1,4	0,0	4,3	9,0	13,9	17,1	16,6	12,9	8,3	4,4	1,8
Ronneby	7,1	−1,5	−1,4	0,5	5,1	10,2	14,3	16,9	16,0	12,4	7,8	4,1	1,2
Karlshamn	7,6	−0,9	−0,9	1,1	5,4	10,5	14,8	17,3	16,4	12,9	8,4	4,6	1,7
Hagshults flygplats	5,6	−3,4	−3,5	−1,0	4,0	9,4	13,4	15,5	14,5	10,8	6,0	2,1	−0,6
Huskvarna	6,5	−2,4	−2,6	−0,2	4,9	10,1	14,5	16,8	15,7	11,6	6,8	3,0	0,3
Jönköping	6,1	−2,6	−3,0	−0,7	4,3	9,3	13,8	16,3	15,2	11,4	6,6	2,7	0,0
Borås	6,3	−2,9	−3,0	−0,4	4,7	10,5	14,2	16,5	15,4	11,4	6,7	2,7	−0,1
Nässjö	5,4	−4,1	−4,1	−1,2	3,9	9,6	13,7	16,1	14,8	10,7	5,7	1,5	−1,3
Växjö	6,5	−2,8	−2,7	−0,1	5,0	10,5	14,6	16,6	15,6	11,6	6,8	2,8	−0,1
Malmö flygplats	8,0	−0,5	−0,7	1,4	6,0	11,0	15,0	17,2	16,7	13,5	8,9	4,9	2,0
Kristianstad	7,7	−0,9	−0,9	1,2	5,9	11,1	15,2	17,4	16,5	12,9	8,3	4,5	1,6
Lund	8,0	−0,7	−0,8	1,3	6,2	11,3	15,2	17,4	16,8	13,5	8,7	4,8	1,9
Alnarp	7,8	−0,8	−1,0	1,2	5,9	11,1	15,0	17,1	16,6	13,3	8,5	4,6	1,8
Ystad	7,8	−0,2	−0,6	1,2	5,3	10,1	14,1	16,7	16,4	13,4	9,2	5,3	2,4

Appendix F Pressure drop diagram

Hjälpmedel

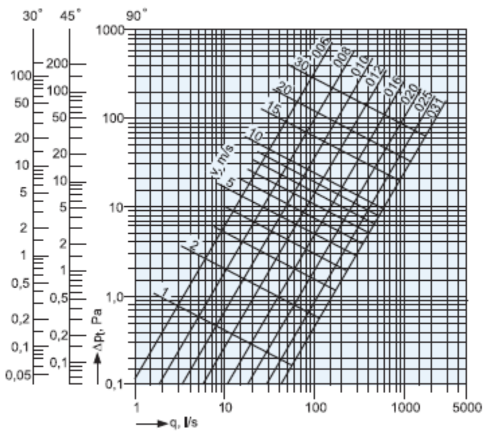
Diagram och formler

Tryckfallsdiagram cirkulära kanaler

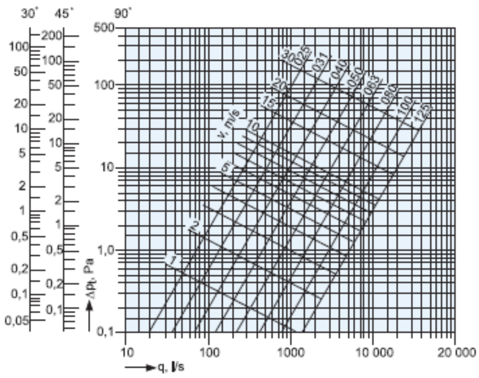


A = Dimension (mm)

Tryckfallsdiagram pressad cirkulär böj



Tryckfallsdiagram segmentbyggd cirkulär böj



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Swegon Luftburna Klimatsystem 2007
www.swegon.se

Figure 12: Pressure drop diagram. Source: SWEGON (Swegon, 2007).

Appendix G Exhaust duct segments diameter calculation

Table 12: Designed exhaust duct segments diameter for TF2, scenario I.

TF2			
Duct segment	**q (l/s)**	**v (m/s)**	**Diameter (mm)**
03-04	85.08	3.5	160
02-03	170.15	4.5	200
01-02	255.23	4	250
AHU-01	340.30	4.5	315

Table 13: Designed exhaust duct segments diameter for TF3, scenario I.

TF3			
Duct segment	**q (l/s)**	**v (m/s)**	**Diameter (mm)**
03-04	151.17	4.5	200
02-03	302.33	5.5	250
01-02	453.50	5.5	315
AHU-01	604.66	5	400

Table 14: Designed exhaust duct segments diameter for TF2+TF3, scenario II.

TF2 + TF3			
Duct segment	**q (l/s)**	**v (m/s)**	**Diameter (mm)**
05-06	157.49	4.5	200
04-05	314.99	4.5	250
03-04	472.48	5.5	315
02-03	629.98	6	315
01-02	787.47	6	400
AHU-01	944.96	5	500

Appendix H AHU selection table

Table 15: Fläktwoods selection table depending on the required airflows. Source: Fläktwoods.

QUICK SELECTION TABLES

eQ Prime / eQ Master / eQL	Air flow m³/s (m³/h)				Filter		Ext. cross-section				
	Max (3,5 m/s over filter)	Air cooler (buildt in cooling unit) face velocity, m/s: 2,0 m/s	2,5 m/s	3,0 m/s	Filter-cassettes	Cassettes	Unit width, mm	Unit width with RHE mm	Unit height, mm single deck	Unit height, mm double deck	Duct connection
005	0,7 (2520)	0,4 (1400)	0,5 (1800)	0,6 (2160)	300x600		800	1050 / 800	476	952	500X300
008 *	1,1 (4032)	0,7 (2520)	0,9 (3240)	1,1 (3960)	800x400		1100	1350 / 1100	576	1152	800x400 Ø 400*
009	1,3 (4680)	0,7 (2520)	0,8 (2880)	1,0 (3600)	600x600		800	1400	776	1552	500x600
011 *	1,6 (5760)	1,0 (3600)	1,3 (4680)	1,5 (5400)	2x500x500		1200	1450 / 1200	676	1352	800x400 Ø 500*
014	1,9 (6840)	1,0 (3600)	1,3 (4680)	1,6 (5760)	600x600 300x600		1100	1400	776	1552	800x500
018	2,5 (9000)	1,4 (5040)	1,8 (6480)	2,1 (7560)	2x600x600		1400	1650 / 1400	776	1552	1100x500
020	2,8 (10080)	1,5 (5400)	1,9 (6840)	2,3 (8280)	600x600 2x300x600 300x300		1100	1800	1076	2152	800x800
	3,3 (11808)	2,2 (7920)	2,7 (9720)	3,3 (11880)	2x600x600 300x600		1700	1700	926	1852	1400x600
	3,8 (13680)	2,1 (7560)	2,6 (9360)	3,1 (11160)	2x600x600 2x300x600		1400	1800	1076	2152	1100x800
	4,5 (16200)	2,6 (9360)	3,3 (11880)	4,0 (14400)	4x400x800		1800	1800	1026	2052	1400x800
	5,0 (18000)	2,6 (9360)	3,3 (11880)	4,0 (14400)	4x600x600		1400	2400	1376	-	1100x1000
	5,7 (20520)	3,2 (11500)	4,0 (14400)	4,8 (17280)	3x600x600 3x300x600		2000	2000	1076	2152	1700x800
	6,3 (22680)	3,4 (12240)	4,2 (15120)	5,0 (18000)	4x600x600 2x300x600		1700	2400	1376	-	1400x1000
	7,0 (25200)	4,3 (15480)	5,3 (19080)	6,4 (23040)	8x500x500		2300	2300	1226	2452	2000x800
	7,3 (26280)	4,1 (14760)	5,1 (18360)	6,1 (21960)	6x600x600		2000	2600	1376	-	1700x1000
	7,9 (28350)	4,3 (15470)	5,4 (19340)	6,4 (23210)	4x600x600 4x300x600 300x300		1700	3000	1676	-	1400x1200
	8,8 (31750)	4,8 (17280)	6,0 (21600)	7,2 (25920)	6x600x600 2x300x600		2300	2600	1376	-	2000x1000
	9,5 (34020)	5,2 (18790)	6,5 (23490)	7,8 (28180)	6x600x600 3x300x600		2000	3000	1676	-	1700x1200
	10,1 (36290)	5,5 (19800)	6,9 (24840)	8,3 (29880)	8x 600x600		2600	2600	1376	-	2200x1000
079	11,0 (39600)	6,1 (22100)	7,7 (27630)	9,2 (33160)	6x600x600 5x300x600 1x300x300		2300	3000	1676	-	2000x1200
090	12,6 (45360)	7,1 (25420)	8,8 (31770)	10,6 (38130)	8x600x600 4x300x600		2600	3300	1676	-	2200x1400
60	13 (47952)	6,66 (23976)	8,33 (29970)	9,99 (35964)	9x600x600		2050	3400	2050	-	1600x1600
62	18 (63504)	8,82 (31752)	11,03 (39690)	13,23 (47628)	12x600x600		2650	3660	2050	-	2200x1600
64	22 (79056)	10,98 (39528)	13,73 (49410)	16,47 (59292)	15x600x600		3250	4000	2050	-	2800x1600
71	20 (73030)	10,14 (36515)	12,68 (45644)	15,21 (54772)	12x600x600 4x300x600		2650	4000	2350	-	2200x1800
73	25 (90914)	12,63 (45457)	15,78 (56822)	18,94 (68186)	15x600x 600 5x300x600		3250	4500	2350	-	2800x1800
80	24 (84672)	11,76 (42336)	14,70 (52920)	17,64 (63504)	16x600x600		2650	4500	2650	-	2200x2000
82	29 (105408)	14,64 (52704)	18,30 (65880)	21,96 (79056)	20x600x600		3250	4500	2650	-	2800x2000
84	36 (131328)	18,24 (65664)	22,80 (82080)	27,36 (98496)	24x600x600		4000	4900	2650	-	3400x2000

A two or three digit code describes the sizes in the eQ range and they indicate the airflow rate at a filter face velocity of 2.5 m/s.
* Can be ordered as eQ Top

Appendix I Calculation of the savings derived of the heat exchanger

Table 16: Values used to calculate the heat energy savings for TF1.

Airflow (l/s)	300	**REAL HE efficiency**	0.7
T target (°C)	21	**Cp (kJ/(kg·K))**	1.2
WH (h/day)	19	**Density (kg/m³)**	1.2

Table 17: Heat energy savings derived of the heat exchanger for TF1.

	TF1	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**		
	Counting	1	1	1	1	0	0	0	0	0	1	1	1		
	days	31	28	31	30	31	30	31	31	30	31	30	31		
	Labour days	22	20	22	21	22	21	22	22	21	22	21	22		
	T. average	-5	-5	-2	3	9	14	17	15	11	5	1	-2		
	diff. Temps	26	26	23	18	12	7	4	6	10	16	20	23		
	T. after HE	13	13	14	16	17	19	20	19	18	16	15	14		
Without HE	**W heat (kW)**	11	11	10	8	5	3	2	2	4	7	9	10	**Total energy**	
	Energy (kWh)	6 641	5 952	5 903	4 358	3 130	1 773	1 120	1 450	2 536	3 995	4 949	5 878	37 677	
With HE	**W heat' (kW)**	3	3	3	2	2	1	1	1	1	2	3	3	**Total energy'**	**Energy savings (kWh)**
	Energy' (kWh)	1 992	1 786	1 771	1 308	939	532	336	435	761	1 198	1 485	1 763	11 303	26 374

Table 18: Values used to calculate the heat energy savings for TF2.

Airflow (l/s)	340.30	**REAL HE efficiency**	0.55
T target (°C)	18	**Cp (kJ/(kg·K))**	1.2
WH (h/day)	12	**Density (kg/m^3)**	1.2

Table 19: Heat energy savings derived of the heat exchanger for TF2.

	TF2	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**		
	Counting	1	1	1	1	0	0	0	0	0	1	1	1		
	days	31	28	31	30	31	30	31	31	30	31	30	31		
	Labour days	22	20	22	21	22	21	22	22	21	22	21	22		
	T. average	-5	-5	-2	3	9	14	17	15	11	5	1	-2		
	diff. Temps	23	23	20	15	9	4	1	3	7	13	17	20		
	T. after HE	8	8	9	11	14	16	17	17	15	12	10	9		
Without HE	**W heat (kW)**	11	11	10	7	5	2	1	1	4	6	8	10	**Total energy**	
	Energy (kWh)	3 008	2 693	2 630	1 852	1 211	529	182	352	920	1 654	2 155	2 617	16 609	
With HE	**W heat' (kW)**	5	5	4	3	2	1	0	1	2	3	4	4	**Total energy’**	**Energy savings (kWh)**
	Energy' (kWh)	1 354	1 212	1 184	834	545	238	82	158	414	744	970	1 178	7 474	9 135

Table 20: Values used to calculate the heat energy savings for TF3.

Airflow (l/s)	604.66	**REAL HE efficiency**	0.55
T target (^oC)	18	**Cp (kJ/(kg·K))**	1.2
WH (h/day)	12	**Density (kg/m^3)**	1.2

Table 21: Heat energy savings derived of the heat exchanger for TF3.

	TF3	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**		
	Counting	1	1	1	1	0	0	0	0	0	1	1	1		
	days	31	28	31	30	31	30	31	31	30	31	30	31		
	Labour days	22	20	22	21	22	21	22	22	21	22	21	22		
	T. average	-5	-5	-2	3	9	14	17	15	11	5	1	-2		
	diff. Temps	23	23	20	15	9	4	1	3	7	13	17	20		
	T. after HE	8	8	9	11	14	16	17	17	15	12	10	9		
Without HE	**W heat (kW)**	20	20	18	13	8	4	1	2	6	11	15	18	**Total energy**	
	Energy (kWh)	5 344	4 785	4 673	3 291	2 152	940	324	625	1 634	2 938	3 829	4 650	29 512	
With HE	**W heat' (kW)**	9	9	8	6	4	2	1	1	3	5	7	8	**Total energy’**	**Energy savings (kWh)**
	Energy' (kWh)	2 405	2 153	2 103	1 481	968	423	146	281	736	1 322	1 723	2 093	13 280	16 232

Table 22: Values used to calculate the heat energy savings for TF4.

Airflow (l/s)	1568.29	**REAL HE efficiency**	0.7
T target (^oC)	21	**Cp (kJ/(kg·K))**	1.2
WH (h/day)	19	**Density (kg/m^3)**	1.2

Table 23: Heat energy savings derived of the heat exchanger for TF4.

	TF4	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**		
	Counting	1	1	1	1	0	0	0	0	0	1	1	1		
	days	31	28	31	30	31	30	31	31	30	31	30	31		
	Labour days	22	20	22	21	22	21	22	22	21	22	21	22		
	T.average	-5	-5	-2	3	9	14	17	15	11	5	1	-2		
	diff. Temps	26	26	23	18	12	7	4	6	10	16	20	23		
	T. after HE	13	13	14	16	17	19	20	19	18	16	15	14		
Without HE	**W heat (kW)**	59	58	52	40	28	16	10	13	23	35	45	52	**Total energy**	
	Energy (kWh)	24 798	22 227	22 043	16 275	11 686	6 620	4 181	5 416	9 471	14 917	18 481	21 948	140 687	
With HE	**W heat' (kW)**	18	18	16	12	8	5	3	4	7	11	14	16	**Total energy’**	**Energy savings (kWh)**
	Energy' (kWh)	7 439	6 668	6 613	4 882	3 506	1 986	1 254	1 625	2 841	4 475	5 544	6 584	42 206	98 481

Appendix J Working period savings due to the rescheduling

Table 24: Savings derived of the rescheduling of the AHU TF1.

TF1			
Hours/day	**days/week**	**hours/week**	
19	7	133	
Improved TF1			
Hours/day	**days/week**	**hours/week**	**SAVINGS (%)**
10	5	50	62.41

Table 25: Savings derived of the rescheduling of the AHU TF2 and TF3.

TF2 & TF3			
Hours/day	**days/week**	**hours/week**	
12	5	60	
Improved TF2 & TF3			
Hours/day	**days/week**	**hours/week**	**SAVINGS (%)**
11	5	55	8.33

Table 26: Savings derived of the rescheduling of the AHU TF4.

TF4			
Hours/day	**days/week**	**hours/week**	
19	5	95	
improved TF4			
Hours/day	**days/week**	**hours/week**	**SAVINGS (%)**
13	5	65	31.58

Appendix K Updating factors for the economic study

Table 27: Table used to define the updating factor that appears in the economic study formula to calculate the maximum affordable cost to achieve an economic benefit of the investment. Source: Roland Forsberg.

Investeringskalkyl 18:5

Nusummefaktor

Nusummefaktorn betecknar summa nuvärde av 1 kr, som utfaller i slutet av varje år under n år.

Tabellen är uppgjord efter

$$\frac{1-(1+i)^{-n}}{i} = \frac{(1+i)^n-1}{1\,(1+i)^n}$$

Tar man hänsyn till index gäller följande uttryck

$$\frac{b^n-1}{(b-1)\,(1+i_{kalkyl})} \text{ där } b = \frac{1+i_{index}}{1+i_{kalkyl}}$$

Om $i_{index} = i_{kalkyl}$ gäller $\frac{n}{1+i}$

Sker utfall i början av året, multipliceras med faktorn $1 + i_{kalkyl}$

Exempel: En investering i år besparar ett företag löpande driftsutgifter om 10 000 kr per år i 5 år. Hur stort är värdet i dag av de samlade besparingarna vid 10 % ränta?

Svar: 3,791 × 10 000 = 37 910

n	Räntesats, %									
år	4	5	6	8	10	12	15	18	20	25
1	0,962	0,952	0,943	0,926	0,909	0,893	0,870	0,847	0,833	0,800
2	1,886	1,859	1,833	1,783	1,736	1,690	1,626	1,566	1,528	1,440
3	2,775	2,723	2,673	2,577	2,487	2,402	2,283	2,174	2,107	1,952
4	3,630	3,546	3,465	3,312	3,170	3,037	2,855	2,690	2,589	2,362
5	4,452	4,329	4,212	3,993	3,791	3,605	3,352	3,127	2,991	2,689
6	5,242	5,076	4,917	4,623	4,355	4,111	3,785	3,498	3,326	2,951
7	6,002	5,786	5,582	5,206	4,868	4,564	4,160	3,812	3,605	3,161
8	6,733	6,463	6,210	5,747	5,335	4,968	4,487	4,078	3,837	3,329
9	7,435	7,108	6,802	6,247	5,759	5,328	4,772	4,303	4,031	3,463
10	8,111	7,722	7,360	6,710	6,145	5,650	5,019	4,494	[illegible]193	3,570
11	8,760	8,306	7,887	7,139	6,495	5,938	5,234	4,656	4,327	3,656
12	9,385	8,863	8,384	7,536	6,814	6,194	5,421	4,793	4,439	3,725
13	9,986	9,394	8,853	7,904	7,103	6,424	5,583	4,910	4,533	3,780
14	10,563	9,899	9,295	8,244	7,367	6,628	5,725	5,008	4,611	3,824
15	11,118	10,380	9,712	8,559	7,606	6,811	5,847	5,092	4,676	3,859
16	11,652	10,838	10,106	8,851	7,824	6,974	5,954	5,162	4,730	3,887
17	12,166	11,274	10,477	9,122	8,022	7,120	6,047	5,222	4,775	3,910
18	12,659	11,690	10,828	9,372	8,201	7,250	6,128	5,273	4,812	3,928
19	13,134	12,085	11,158	9,604	8,365	7,366	6,198	5,316	4,844	3,942
20	13,590	12,462	11,470	9,818	8,514	7,469	6,259	5,353	4,870	3,954
25	15,622	14,094	12,783	10,675	9,077	7,843	6,464	5,467	4,948	3,985
30	17,292	15,372	13,765	11,258	9,427	8,055	6,566	5,517	4,979	3,995
40	19,793	17,159	15,046	11,925	9,779	8,244	6,642	5,548	4,997	3,999
50	21,482	18,256	15,762	12,233	9,915	8,304	6,661	5,554	4,999	4,000

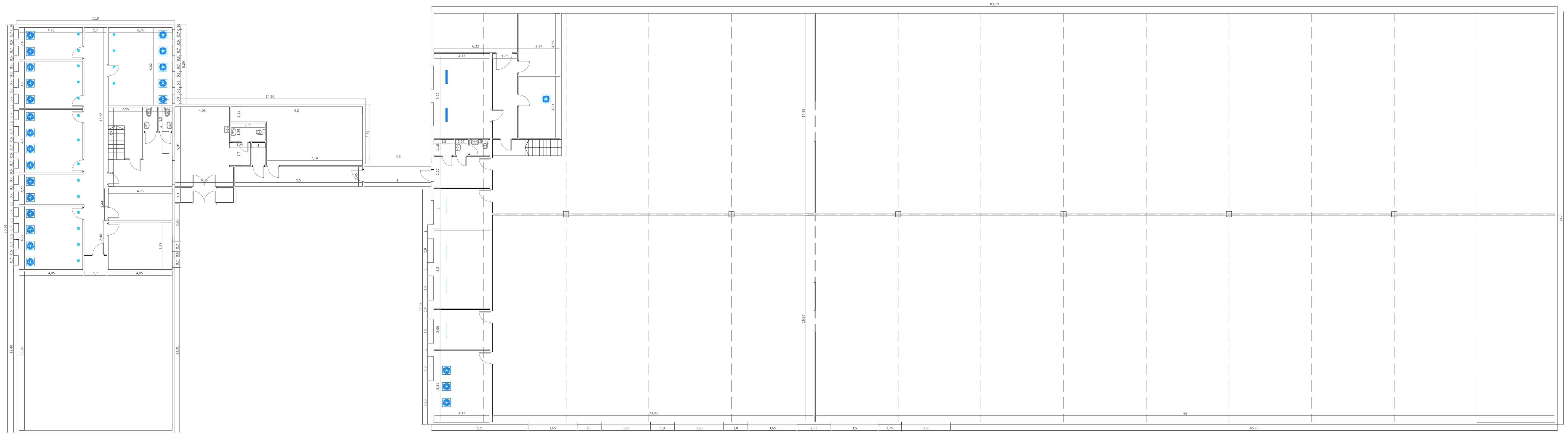
Appendix L Industrial energy prices

The prices were given by another company that could be comparable to that studied in this thesis project.

Table 28: Energy prices for a similar company in Gävle the year 2017.

2017	DISTRICT HEATING		ELECTRICITY	
	Energy (MWh)	Price (SEK)	Energy (kWh)	Price (SEK)
JAN	131.16	83 438	97051	120 203
FEB	107.25	69 836	90353	112 229
MAR	94.1	64 135	99290	113 887
APR	80.3	56 460	85448	78 503
MAY	37.11	34 365	91681	85 490
JUN	7.32	18 271	80208	73 196
JUL	4	16 966	51942	53 348
AUG	8.43	19 281	90411	92 374
SEP	28.2	29 131	93369	97 482
OCT	70.74	51 838	102994	99 246
NOV	98.76	66 142	100437	119 733
DEC	110.83	72 899	88811	109 880
TOTALS	778.2	582 762	1071995	1 155 571
	SEK/MWh	748.86	SEK/kWh	1.08

Appendix M Building drawings



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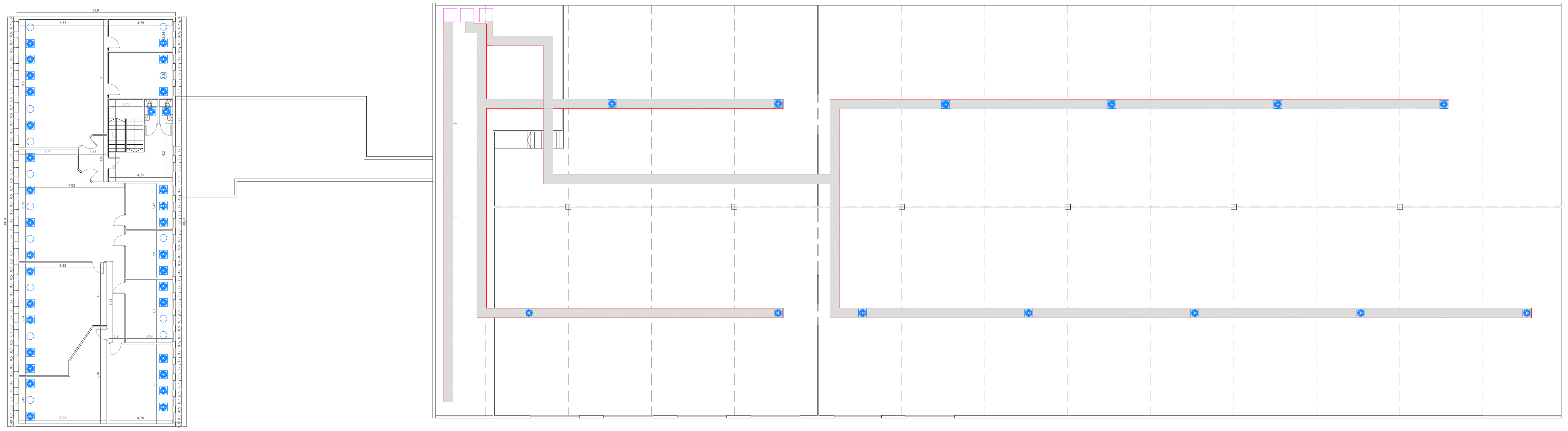
	LINEAL SUPPLY GRID (1 METRE)
	DIFFUSER
	CLOSED DIFFUSER
	SUCTION HOOD
	VENTILATION SUPPLY DUCT
	VENTILATION EXHAUST DUCT

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:300	A3	MAY 2018	CURRENT SITUATION - GROUND FLOOR	01
				REF _		Page 1 of 1



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	CLOSED DIFFUSER
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	VENTILATION EXHAUST DUCT

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
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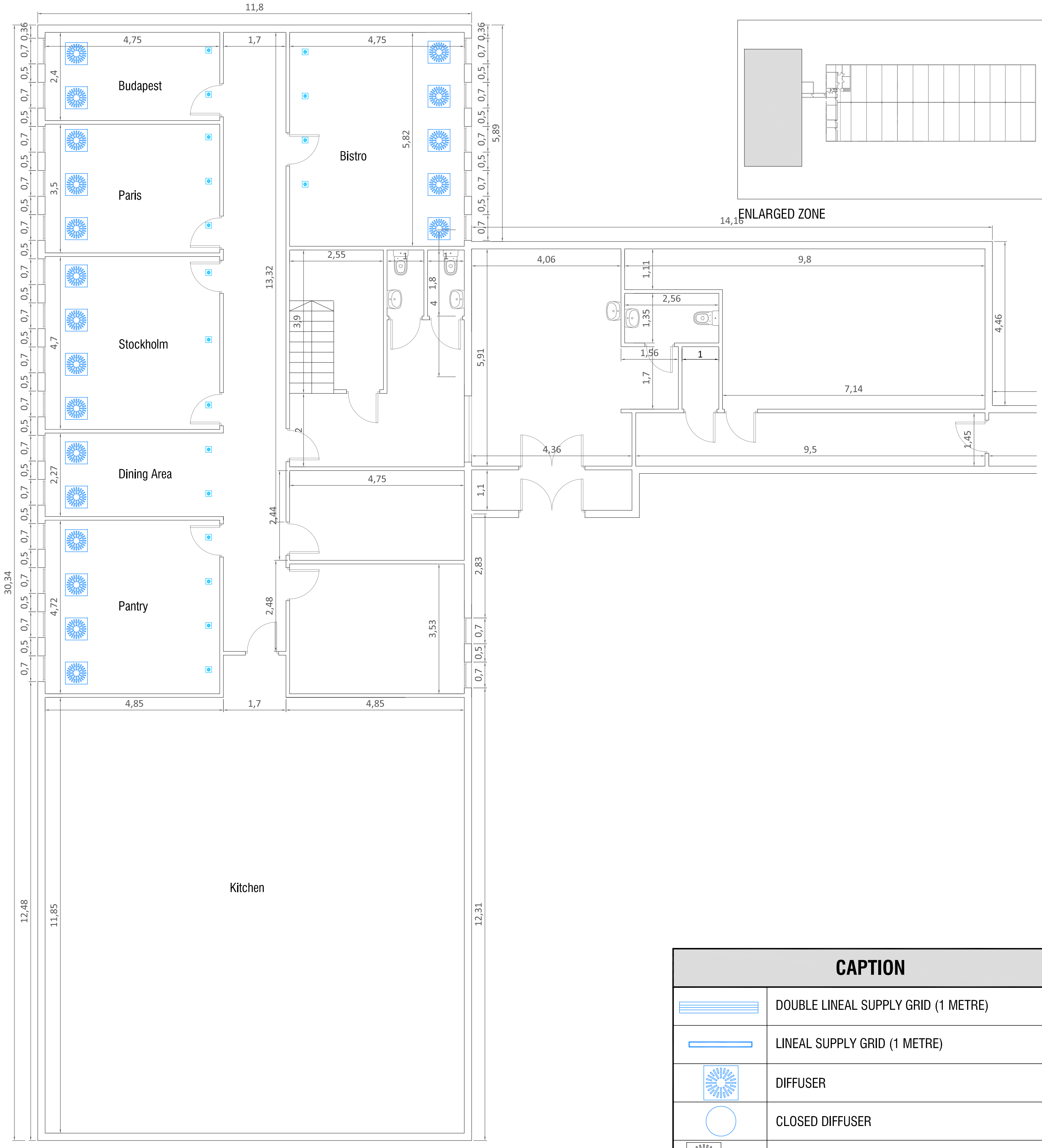
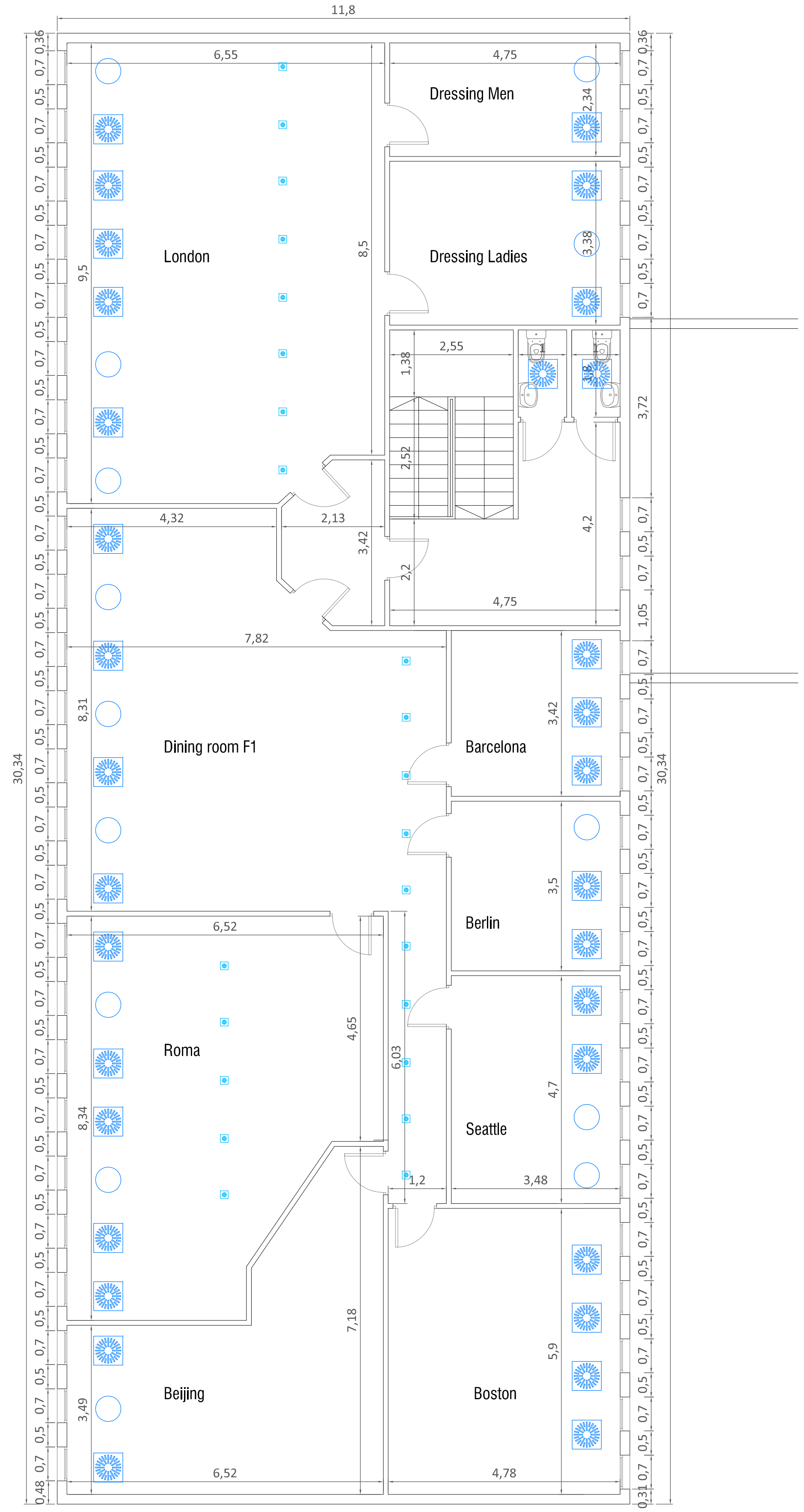


GROUND FLOOR



FIRST FLOOR

CAPTION

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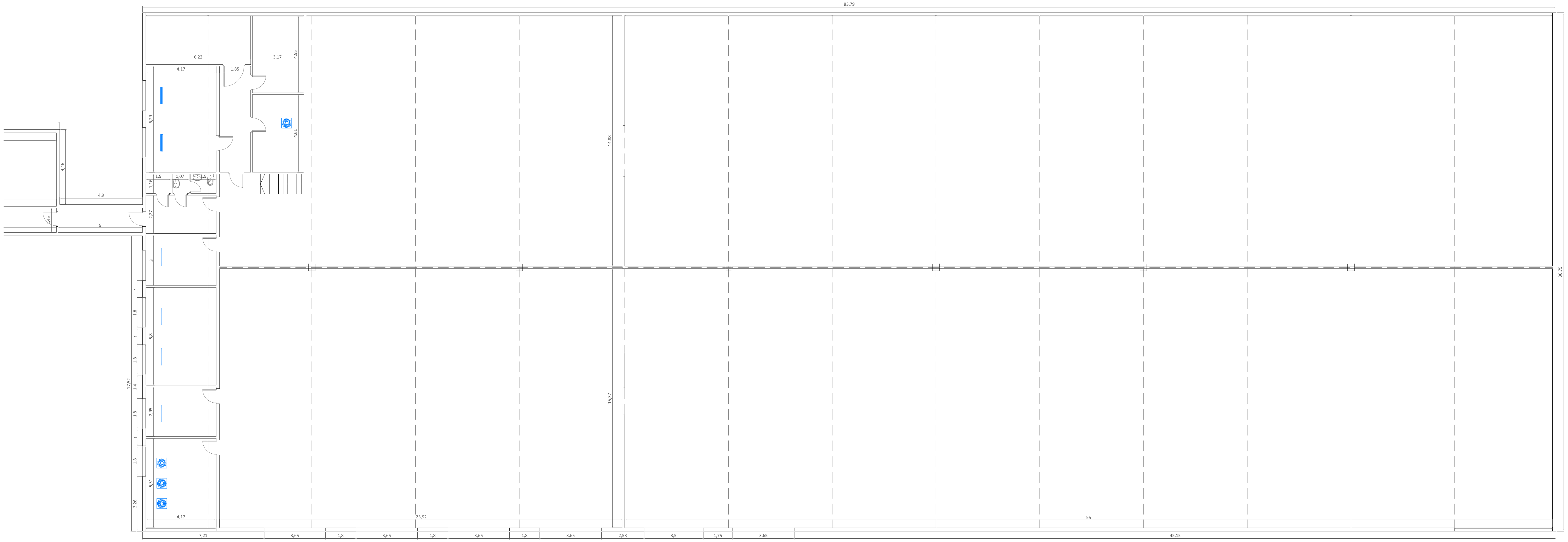
	SUCTION HOOD
	VENTILATION SUPPLY DUCT
	VENTILATION EXHAUST DUCT

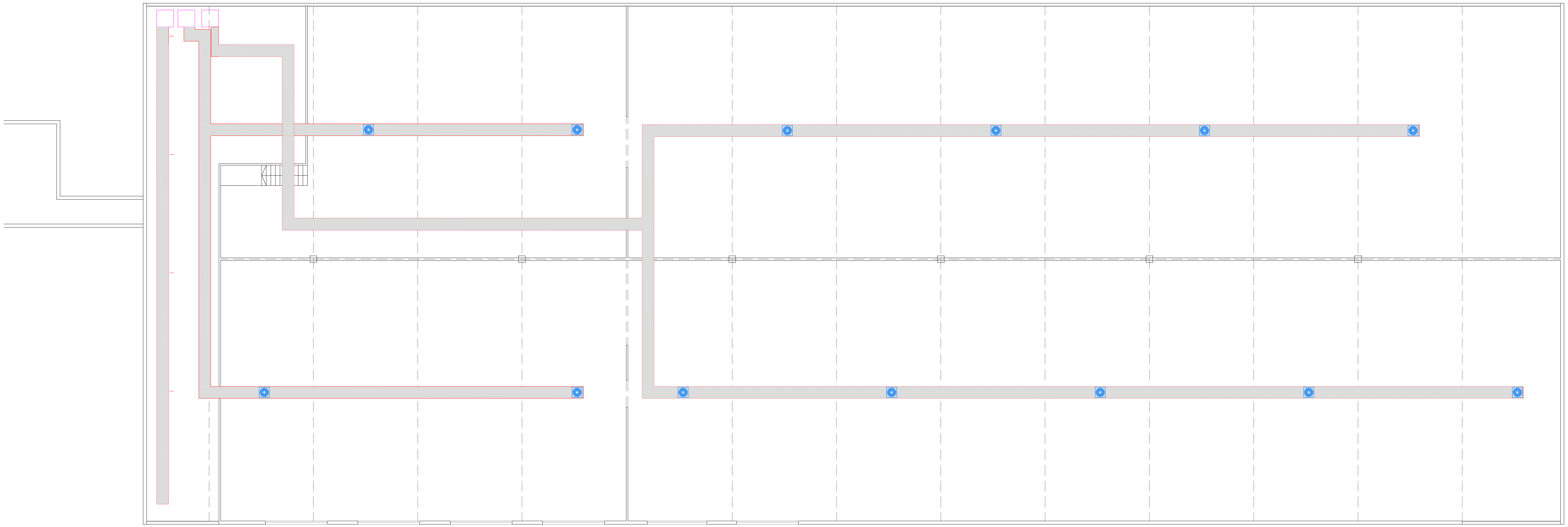
PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:150	A3	MAY 2018 REF _	CURRENT SITUATION - COOKING SCHOOL - GROUND FLOOR AND FIRST FLOOR	03 Page 1 of 1



ENLARGED ZONE

CAPTION
DOUBLE LINEAL SUPPLY GRID (1 METRE)
LINEAL SUPPLY GRID (1 METRE)
DIFFUSER
CLOSED DIFFUSER
SUCTION HOOD
VENTILATION SUPPLY DUCT
VENTILATION EXHAUST DUCT

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:250	A3	MAY 2018 REF –	CURRENT SITUATION - WAREHOUSE - GROUND FLOOR	04 Page 1 of 1



ENLARGED ZONE

CAPTION	
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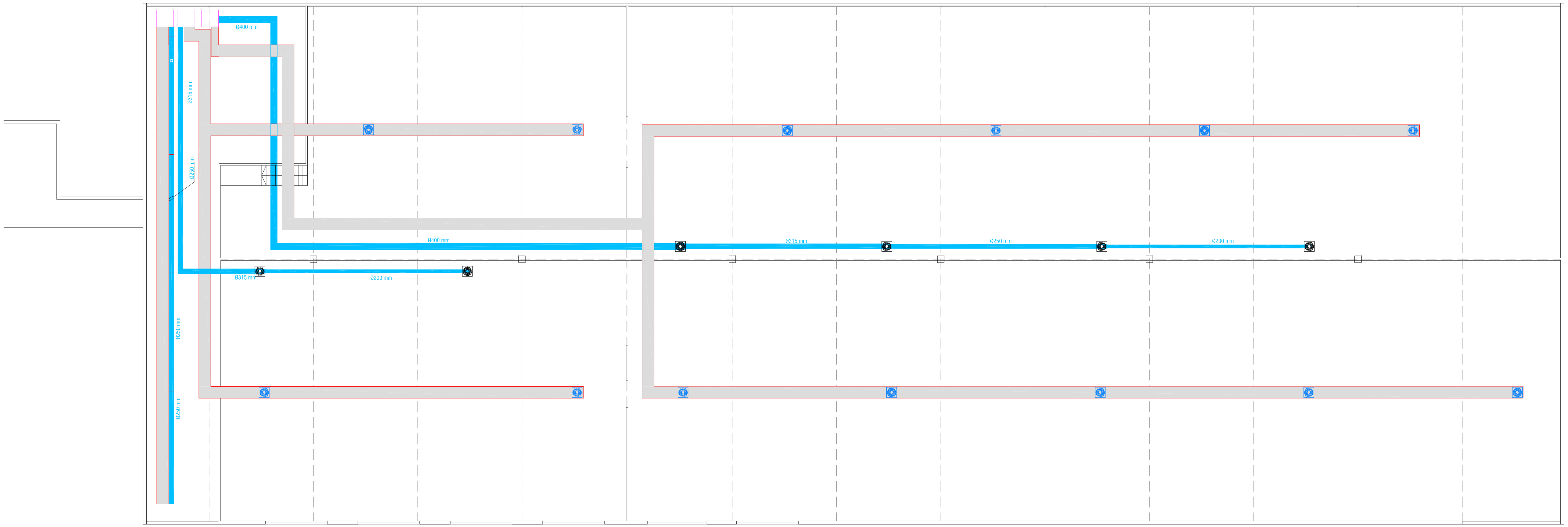
	LINEAL SUPPLY GRID (1 METRE)
	DIFFUSER
	CLOSED DIFFUSER
	SUCTION HOOD
	VENTILATION SUPPLY DUCT
	VENTILATION EXHAUST DUCT

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:250	A3	MAY 2018	CURRENT SITUATION - WAREHOUSE - FIRST FLOOR	05
				REF _		Page 1 of 1



CAPTION	
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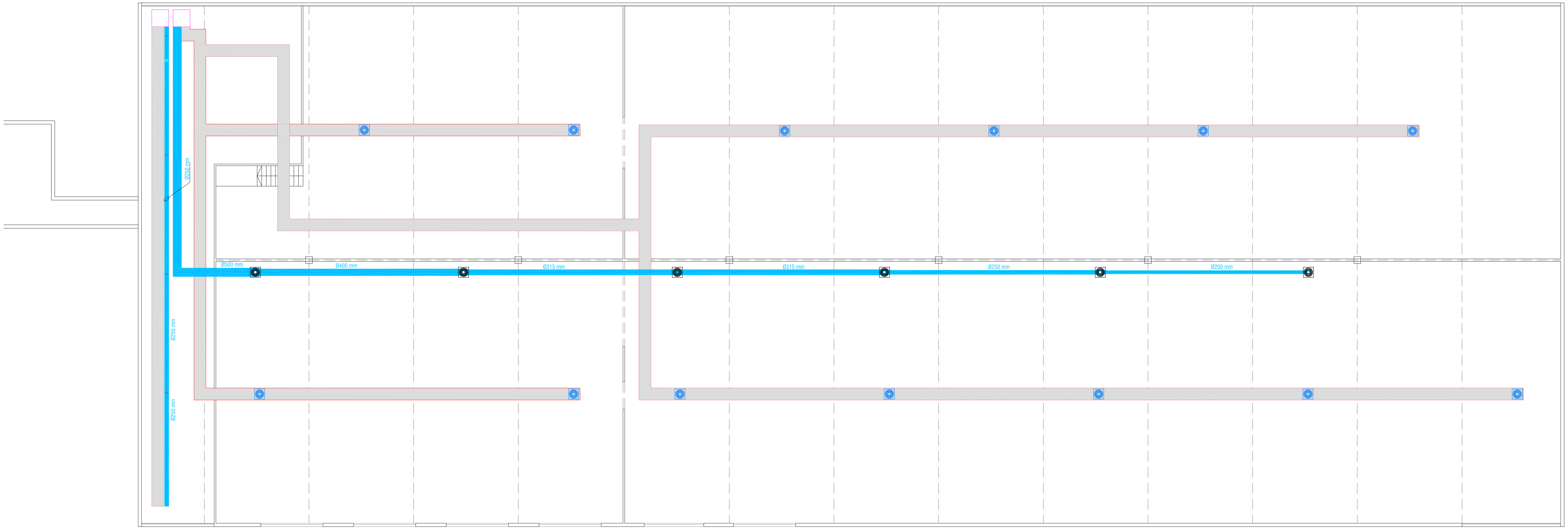
	CLOSED DIFFUSER
	SUCTION HOOD
	VENTILATION SUPPLY DUCT
	VENTILATION EXHAUST DUCT

ENLARGED ZONE

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:250	A3	MAY 2018 REF _	SCENARIO I - SOLUTION	06 Page 1 of 1



ENLARGED ZONE

CAPTION	
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	SUCTION HOOD
	VENTILATION SUPPLY DUCT
	VENTILATION EXHAUST DUCT

PROJECT AUTHOR	PROJECT TITLE	SCALE	FORMAT	DATE	DRAWING	DR NUMBER
JAVIER IGLESIAS ESTELLES	Enhancement of the ventilation system in an industrial plot	1:250	A3	MAY 2018 REF _	SCENARIO II - SOLUTION	07 Page 1 of 1